Estimation and Evaluation of Municipal Solid Waste Management System by Using Economic-Environmental Models in Taiwan(Dissertation_全文)

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Ph.D. Dissertation

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Abstract

As the economic development arises to a great extent all over the world, the contemporary lifestyle is significantly changed. Recent studies argued that unsustainable consumption pattern is a driving factor of the environmental loads, particularly the generation and discards of municipal solid waste (MSW). Quantitatively reexamining the current consumption behavior from the perspective of sustainability is particular important. However, hardly any studies provide a holistic quantitative methodology for quantifying the consumer's behavior and for analyzing its impacts on MSW management system. Thus, this study aims at developing a methodology for (1) establishing a detailed quantitative modeling system of the consumer's behavior; (2) clarifying the impacts of the consumer's behavior and policy interventions on the MSW discard rate in terms of waste fraction simultaneously by developing an quantitative model; (3) facilitating the MSW management system by using the backcasts, the estimates, and the future projections (the ex-ante forecasting) of MSW discards generated by the models set forth in this study. The main achievements are as the followings:

At the beginning of this study, a holistic quantitative methodology is established to simulate the MSW conversion processes during the consumption activities, so that the impacts of the individual's consumption on MSW discards can be exploited. The driving factors of the citizens' lifestyle and their relationships with the environmental loads are discussed; subsequently, the lifestyle analysis is induced into the analytic model of the consumer's behavior; then, the individual's MSW discard rate by waste fraction is analyzed based on the consumer's behavior, which is driven by the lifestyle changes, as well as the relevant policy interventions. Hence, the impacts of the individual's consumption expenditure and the effectiveness of policy measures on the MSW discard rate can be clarified simultaneously with the established estimation model system of MSW discards. Concrete policy measures in terms of waste fractions and a more sustainable pattern of consumption can then be proposed. The capacity planning and the estimation of Greenhouse gas (GHG) emission of the MSW treatment and disposal facilities can be conducted as well on the basis of the estimation model system of MSW discards.

After designing the quantitative methodology, the models are validated for a case study of Taiwan. Taiwan has the typical characteristics and experiences of a developing economy

where the economy is growing rapidly and makes dents on every phase of life. In addition, such progress accompanies large amounts of waste discards and GHG emission.

To start with the Taiwanese case study, a preliminary lifestyle analysis is conducted by analyzing the lifestyle variables, which comprises of the representative socioeconomic indices and household characteristics in Taiwan. High correlations exist among the socioeconomic variables, suggesting that an intrinsic relationship may exist among the variables. After that, the MSW management progress in Taiwan is comprehensively reviewed. In the development of the estimation model system of MSW discards, initially, an adaptive expectation permanent income hypothesis consumption function is found to well explain the behaviour of annual per capita overall consumption expenditure. Next, the individual's consumption expenditure can be well simulated by using the linear expenditure system (LES) model and the multinomial logit (MNL) model, hierarchically. The results not only generate accurate estimates of an individual's consumption expenditure but also provide an explicit and quantitative structure of the consumer's preferences during the estimation period by considering the changes in lifestyle. Mainly, the individual's consumption expenditures on "food" and "housing" occupy the most portions in his/her subsistence level of consumption while the individual spends more on "housing", "medicines & medical care", and "amusement & education" on his/her non-subsistence level of consumption. In developing the MSW discard model, the relationships among the MSW discards, consumption items, and the important MSW policy measures are quantified. The accurate estimates of MSW discards by waste fraction during the estimation and ex-post forecast period certify the model as a forecasting tool to project annual per capita MSW discards, thus enabling planning, designing, and executing MSW system by municipalities. The results of the MSW discard model indicate that per capita consumption expenditures on "food", "household appliances", and "amusement & education" are the main driving factors for the discards of the majority of waste fractions in Taiwan from 1992 to 2004, and the performance of important MSW policy measures are evaluated as well. With regard to the model implication, consumers can try to eliminate unnecessary consumption, producers can rethink their responsibility on reducing MSW discards during the consumption process, and municipalities can evaluate the efficiency of existing policy measures and improve it upon based on the quantitative analysis. Meanwhile, an economically efficient market for

recycling materials from MSW is required to be established while the recycling rate is promoted significantly in recent years. The backcasts of MSW discards during the period of 1981-1991 provide an image for the real situation in the past period when no official records were available. Next, the future projection of MSW discards by waste fraction is obtained by the scenario analysis. Possible ranges of MSW discards are projected up to 2021 considering the consumption levels and MSW policy effects.

By using the model fitting results in the earlier stages, the required capacity of MSW treatment and disposal system are then calculated. The analysis results suggest that the capacity of the landfilling is crucially in need, and sophisticated covering operation procedures should be adopted at existing landfill sites for stabilizing the dumped ashes. New incinerators should be constructed in the earlier 2010's for precaution. In addition, cross-prefecture MSW collection and treatment networks should be promoted. The GHG emission from the corresponding MSW treatment and disposal processes are calculated using the projections of MSW discards by waste fraction as well, applying the IPCC 2006 methodology. The analysis results show that reduction and recycling of food waste, paper waste, and plastic waste would efficiently prevent the GHG emission from MSW treatment and disposal system.

From the analysis results, it is concluded that the consumer's behavior and its influences on the MSW discards are analyzed, so that a sustainable lifestyle can be formed by eliminating the potential "excess consumption" in the individual's consumption expenditure. Tangible strategies involving the ideas of "dematerialization", "slower consumption", and "ecological modernisation" can be made. The design of concrete policy measures can be further achieved through the established models in terms of waste reduction, recycling programs, recovery and conservation of the soil layer along with the biosphere, capacity planning of MSW treatment and disposal system, as well as the prevention of global warming from the perspective of MSW management. To sum up, the findings of this study will contribute to the policy design towards the sustainable lifestyle and a low waste society.

Keywords: Lifestyle Changes; Consumer's Behavior; Municipal Solid Waste Management; Capacity Planning; Global Warming; Econometric Modeling.

アブストラクト

経経済発展が世界中へ広がるにつれて、現代のライフスタイルは大きく変わってきた。最近の研究では、持続可能ではない消費パターンが環境負荷、特に都市ごみの発生や排出、の駆動因子になると論じている。持続可能性の視点から現在の消費活動を量的に再精査することが重要である。しかし、消費者行動の定量化や都市ごみのマネジメントシステムへの影響分析のための総体的で定量的な手法を与える研究はほとんど無い。そこで本研究では、(1)消費者行動の詳細で定量的なモデリングシステムを構築し、(2)定量的モデルを作ると同時にごみ種類ごとに都市ごみ排出率や政策介入の都市ごみ排出率への影響を明らかにし、そして(3)モデルを用いた都市ごみ排出量の過去推計（バックキャスト）、現在推計、将来推計（フォーキャスト）によって都市ごみ管理システムを促進するための、方法論を開発することを目的とした。主な成果は次の通りである。

本研究の最初の段階では、消費活動における都市ごみ変換プロセスをシミュレートする総体的で定量的な方法を開発し、個人消費が都市ごみ排出量に与える影響を明らかにした。まず、市民のライフスタイルを駆動する因子とその環境負荷との関係を論じ、続いて消費者行動の分析モデルにライフスタイル分析を導入した。そして、ごみ種類別のそれぞれの都市ごみ排出率を、ライフスタイル変化や関連した政策介入によって引き起こされる消費者の行動に基づいて分析した。その結果、個人の消費支出と政策の有効性が都市ごみ排出率に与える影響を、開発した都市ごみ排出量推計モデルシステムを用いて、同時に明らかにできた。またその上で、ごみ種類に対する具体的な政策と持続可能的な消費パターンを提案した。また、都市ごみ排出量の推計モデルシステムをベースとして、都市ごみ処理処分能力を設計し、そこからの温室効果ガス排出量を推計した。

定量的な手法を設計した後、台湾のケーススタディでモデルを検証した。経済が急速に成長しかつ生活のあらゆる面で変化した台湾は、発展経済の典型的な特徴と経験を有している。さらに、その発展は多量のごみと温室効果ガスの排出を伴っている。

台湾のケーススタディを行うにあたり、簡単なライフスタイル分析として、台湾の代表的な社会経済指標や家庭特性などのライフスタイル変数の分析を行なった。その結果、社会経済指標間には高い共線性があり、変数間に本質的な関係が存在すると考えられた。続いて、台湾の都市におけるごみ管理のこれまでの発展について総合的にレビューした。都市ごみ排出量推計モデルシステムの開発において、最初に、年間一人当たり全消費支出の行動を説明するために、恒常所得仮説適合期待消費関数を求めた。次に、線形支出体系（LES）モデルと多項ロジット(MNL)モデルを階層的に用いることにより、個人消費支出をシミュレートした。その結果、個人消費支出の正確な推計が得られただけでなく、ライフスタイル変化を考えることにより、推定期間において明白で定量的な消費者選好の構造を得た。主に「食料」と「住居」の個人消費支出は最低必要レ

ベルの消費が大きな割合を占め、「住居」、「医薬保健」、「娯楽教育」の個人消費支出は最低必要レベルを越える過剰消費であった。都市ごみ排出モデルを作成する過程で、都市ごみ排出量、消費項目、そして重要な都市ごみ政策の関連を定量化した。シミュレーションにより推計期間と事後予測期間でごみ量を正しく推計できること示し、このモデルがごみ組成ごとに一人当たりの都市ごみ排出量を予測できるツールとして有効であることを証明した。このモデルは自治体の都市ごみシステムの計画や設計を可能にする。　考察により 1992 年から 2004 年の台湾での多くごみ種類は「食料」、「家電」、「娯楽教育」の消費支出が排出の誘発因子となっていることが明かとなった。さらに、重要な都市ごみ政策の効果についても同様に評価した。モデルからは、消費者は不必要な消費を切り詰めることができ、生産者は消費プロセスでの都市ごみ排出量の削減責任を再考でき、自治体は今の政策の効果を評価して定量的分析をベースにそれを改善できることが示唆された。さらにモデルから、近年にリサイクル率を上昇させる一方で、都市ごみ再生資源の経済的で効率的な市場を成立させることが求められた。1981 年から 1991 年の都市ごみ排出量の過去推計（バックキャスト）は、公式のデータが利用できない過去の期間の現実的なイメージを与えた。次にシナリオ解析によって、ごみ種類ごとの都市ごみ排出量の将来推計を得た。都市ごみ排出量のとりうる範囲を、消費水準と都市ごみ政策の効果を考えながら、2021 年まで推計した。

初期段階におけるモデルフィッティングの結果を踏まえて、都市ごみの処理処分システムの要求される処理能力を計算した。分析結果より、埋立容量は極度に逼迫しており、埋め立てられた灰を安定化する最新の被覆方式を現在の埋立処分場に適用すべきこと、予防措置として新しい焼却炉を 2010 年代の初期に建設すべきこと、加えて、広域的な都市ごみ収集と処理ネットワークを促進すべきことを指摘した。

ごみ種類ごとの都市ごみ排出量を予測し、IPCC2006 の手法を適用して都市ごみ処理処分プロセスからの温室効果ガス排出量を計算した。計算結果より、食品、紙、プラスチックのごみを減量化しリサイクルすることが温室効果ガスを効果的に低減させることが示唆された。

以上の研究の結果、持続可能なライフスタイルとその都市ごみ排出量との関係は、個人の消費支出の中に潜在する「過剰な消費」を減らすことによって形作ることができると結論付けられた。その低減のためには、「脱物質化」、「スローな消費」、「エコロジカルな現代化」のアイデアを含む具体的な戦略が考えられる。さらに、本研究で作成したモデルを通して、ごみ減量化やリサイクルプログラム、生物圏が伴う土壌層の復旧や保全、都市ごみ処理処分システムの能力設計、そして都市ごみ管理の視点からの温暖化防止に関して、具体的な政策が立案できる。これらの知見が、持続可能なライフスタイルと低ごみ排出社会に向けた政策設計に貢献すると考えられる。

Keywords: ライフスタイル変化、消費者行動、都市ごみ管理、処理能力設計、地球温暖化、計量経済モデル

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Chapter 1 Introduction

1.1 Background

Industrialization and urbanization have advanced rapidly over the past few decades. How the economics develops in harmony with the environment has remained an ongoing classical debate. The process of how the consumption promotes the welfare, both monetarily and environmentally, has been highlighted (Lintott, 1998). However, as the time progresses, the phenomenon of "mass production, mass consumption, and mass discards" appears to be a primary characteristic in modern societies, particularly in developing countries and economies. The anthropogenic economic activities, such as consumption and production, drive all the aspects of people's lifestyle, and are considered as the key driving force of global environmental problems (UN, 1993; Vitousek et al., 1997; Wijst and Groot-Marcus, 1999; Jackson and Marks, 1999; Jalas, 2002; OECD, 2002; Burger, 2002; O'Hara and Stagl, 2002; Spangenberg and Lorek, 2002; Rood et al., 2003; Gilg et al., 2005; Schor, 2005; UNEP, 2006; Nansai et al., 2008); furthermore, the changes in lifestyle is regarded as an influential factor of unsustainable consumption (Noorman et al., 1999; Gilg et al., 2005; Kanamori and Matsuoka, 2006; Fujiwara et al., 2007).

The consumer's behavior originating from the contemporary lifestyle has a great potential to enlarge the environmental loads, particularly for municipal solid waste (MSW) generation and discards. Definitions of municipal solid waste vary from country by country in terms of waste collection operation, sources of waste, or waste composition (Burnley, 2001). Among the definitions of MSW in use, the definition provided by OECD seems to be widely adopted, which defines the MSW based on the collection operation and sources. According to OECD's definition, MSW generation denotes the waste generated at the following sources, including residential areas, commercial districts, office buildings, institutions, etc. (OECD, 2007). Normally, out of MSW generation, a portion is either recycled or treated by the MSW generators; the rest of the portion is deposited and managed by the local government like municipalities.

Precisely, in this study, the portion of MSW generation that is collected, treated, and disposed by the municipalities is defined as MSW discards (see Fig. 1-1). The estimation of the amount of MSW discards is necessary for rational planning and designing MSW management system. This task is of particular importance for the developing countries, in which inappropriate MSW treatment and disposal facilities are not well organized. For this purpose, it is imperative to clarify and quantify the relationship of the driving factors for MSW, not only for the quantity but for the waste composition so as to rationally tailor the system in keeping with techno-eco-environmental considerations. Concrete and efficient policy measures on eliminating the amount of MSW generation and discards can be made only if the decisive driving factors of MSW generation/discards are clarified. In addition, two important issues of the MSW management system can be significantly promoted with the precise estimation of MSW discards — the capacity planning as well as the environmental loads of MSW treatment and disposal system, especially the greenhouse gas (GHG) emission.

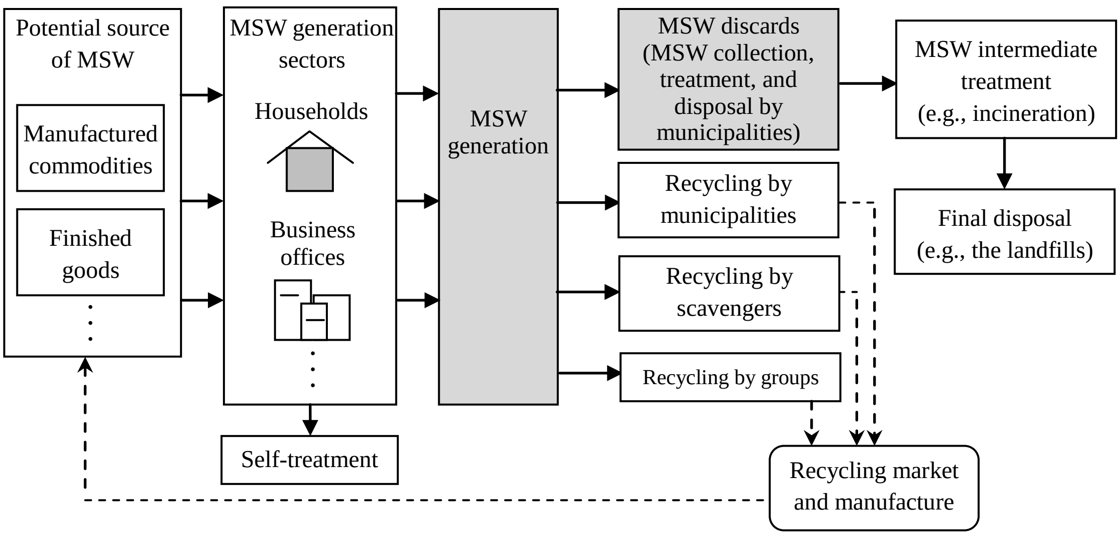

Fig. 1-1 The conceptual flow for the fate of MSW.

For developing countries and economies, the capacity planning of MSW treatment and disposal facilities is one of the most important issues for contemporary MSW management system. Inappropriate intermediate treatment and disposal of MSW would lead to detrimental damage to the human health and natural environment (Dyke et al., 1997; Hamer, 2003). Also, the MSW discard rate in terms of the socioeconomic changes should be further considered in the capacity planning of MSW treatment and disposal system.

Nowadays, the global warming is a critical threat for the sustainability of the contemporary life system, and the scientific evidences suggest that global warming is significantly enhanced by the GHG emission from anthropogenic activities (Kerr, 2006; IPCC, 2007). Recently, GHG emission emitted during the MSW treatment and disposal system are of much concern, and is taken into account in the context of global warming assessment (Grag et al., 2004; Kummar et al., 2004; Mendes et al., 2004; Mor et al., 2004; Talyan et al., 2007; Jha et al., 2008; Liamasanguan et al., 2008; Marmo, 2008; Mondini et al., 2008). With the life-cycle perspective, the options of appropriate MSW treatment technology are particularly highlighted. Especially for developing countries and economies, it is imperative to consider the estimation of the potential GHG emission during the MSW treatment and disposal system before adopting the technology options of the MSW treatment and disposal facilities. Moreover, GHG emission from MSW treatment and disposal system is seldom considered in the GHG account system in developing countries and economies. Despite some studies calculated GHG emission during the landfilling, hardly any studies estimate GHG emission in terms of incineration, which has become a popular technology option in the countries where the landfilling space is unavailable. A more comprehensive assessment methodology is required for MSW management system.

1.2 Purpose of Study

Indeed, consumption activities play a key role in human economic system, and subsequently drive the generation and discard of MSW. Since the unsustainable pattern of consumption has received a great concern in recent decades, hardly any studies provide an integrated or holistic quantitative methodology for quantifying the consumer’s behavior and analyzing its impacts on MSW management system.

Hence, the first objective of this study is to develop a holistic quantitative methodology to simulate the MSW conversion processes during the human consumption activities, so that the impact of the individual's consumption on MSW management system can be exploited. At the beginning, the driving factors of the citizens' lifestyle and their relationships with the environmental loads are discussed; subsequently, the lifestyle analysis is induced into the analytic model of the consumer's behavior; consequently, the individual's MSW discard rate in terms of waste fractions is analyzed based on the consumer's behavior, which is driven by the lifestyle changes and the relevant policy interventions. By coupling the quantitative modeling for the consumer's behavior and his/her MSW discard rate on the basis of the lifestyle changes and policy effects, the impacts of the individual's consumption expenditure and the effectiveness of policy measures on the MSW discard rate can be clarified simultaneously. Thus, concrete and efficient policy suggestions in terms of waste fractions and a more sustainable pattern of consumption can be proposed.

After the establishment of the quantification models of MSW discards, the second objective of this study is to apply the models to the MSW management system. As earlier discussed, the capacity planning and GHG emission of the MSW treatment and disposal facilities can be achieved on the basis of the estimates of the MSW discard rate by waste fraction.

Maintaining the required capacity and performance of the MSW treatment and disposal system is one of the most important missions for the municipalities under the increasing public concerns on the location and sanitary conditions of the facilities, i.e. the "NIMBY" (not in my backyard) phenomenon. The established models of MSW discards by waste fraction can provide reliable future projections of the amount of MSW discards so as to design the optimal and required capacity of the MSW treatment and disposal system.

Accounting for the global warming, this study at the end applies the established models of MSW discards in terms of waste fractions to estimate the GHG emission from the MSW treatment and disposal system, by using the well IPCC 2006 methodology, the most convincing one to date. Through the analysis results, concrete MSW management strategies can be proposed in the context of the reduction of GHG emission. Furthermore, the impact of the MSW treatment and disposal under current technology choices on GHG emission would be clearly revealed. Such assessment not only is beneficial for examining the sustainability of the MSW treatment and disposal system, but facilitates the recycling and reuse measures on MSW in the context of global warming. This especially requires the continuing interest in MSW management system.

After the design of the conceptual models, the models are validated for a case study of Taiwan. Taiwan has the typical characteristics and experiences of a developing economy. The economy is growing rapidly and makes dents on every phase of life, meanwhile accompanying large amount of waste discards as well as GHG emission. Following the lessons of developed countries, the government has imposed lots of policy measures reducing the waste generation rate, and the improvement of the MSW management is the key target for the national environmental plan (TEPA, 1998).

To date, quantitative models on the relationships among consumption, policy effects, as well as MSW discards and its policy implications, are hardly available. Thus, the specialist and contributions of this study will be the followings: (1) establishing a detailed quantitative modeling system of the consumer's behavior; (2) clarifying the impacts of the consumer's behavior and policy interventions on the MSW discard rate in terms of waste fraction simultaneously by developing an quantitative model; (3) facilitating the MSW management system by using the backcasts, the estimates as well as the future projections (the ex-ante forecasts) generated by the models set forth here in terms of the capacity planning of the MSW treatment and disposal system and its potential on the GHG emission.

1.3 Outline of Research

According to the research purpose, this study is organized as follows:

By reviewing the literatures, Chapter 2 makes an attempt to analyze the effects of the individual's consumption on MSW discards, to clarify the influential factors of MSW discards, to conclude the current development of the quantification models in terms of MSW discards, and subsequently, to propose a conceptual model for the material conversion during the consumption process.

In order to substantially formulating the material conversion during the consumption process, Chapter 3 establishes a holistic methodology of the estimation model system of MSW discards, which comprises the consumption forecasting model, the consumer’s behavior model, and the MSW discard model. Detailed econometric modeling techniques are described in this chapter. By the estimation model system, annual per capita consumption expenditure, its distribution among the commodities, and its impact on MSW discards of respective waste fraction can be quantitatively simulated on the basis of the lifestyle changes and policy effects.

Based on the established estimation model system on MSW discards, Chapter 4 extends its application on the MSW management system to the capacity planning of the MSW treatment and disposal system and the estimation of the GHG emission during the MSW processing.

After constructing the conceptual and quantitative methodology on estimation model system on MSW discards, Chapter 5 makes an attempt to validate the models for the case of Taiwan, which has experienced rapid economic growth and decreasing environmental quality in the past decades. Based on the analysis results, concrete suggestions for policy measures and implications can be proposed.

Consequently, Chapter 6 summaries the findings and accomplishment of this study, and further prospects the future extension and application of the models set forth here. Fig. 1-2 provides an overall framework and the linkages among the chapters of this study.

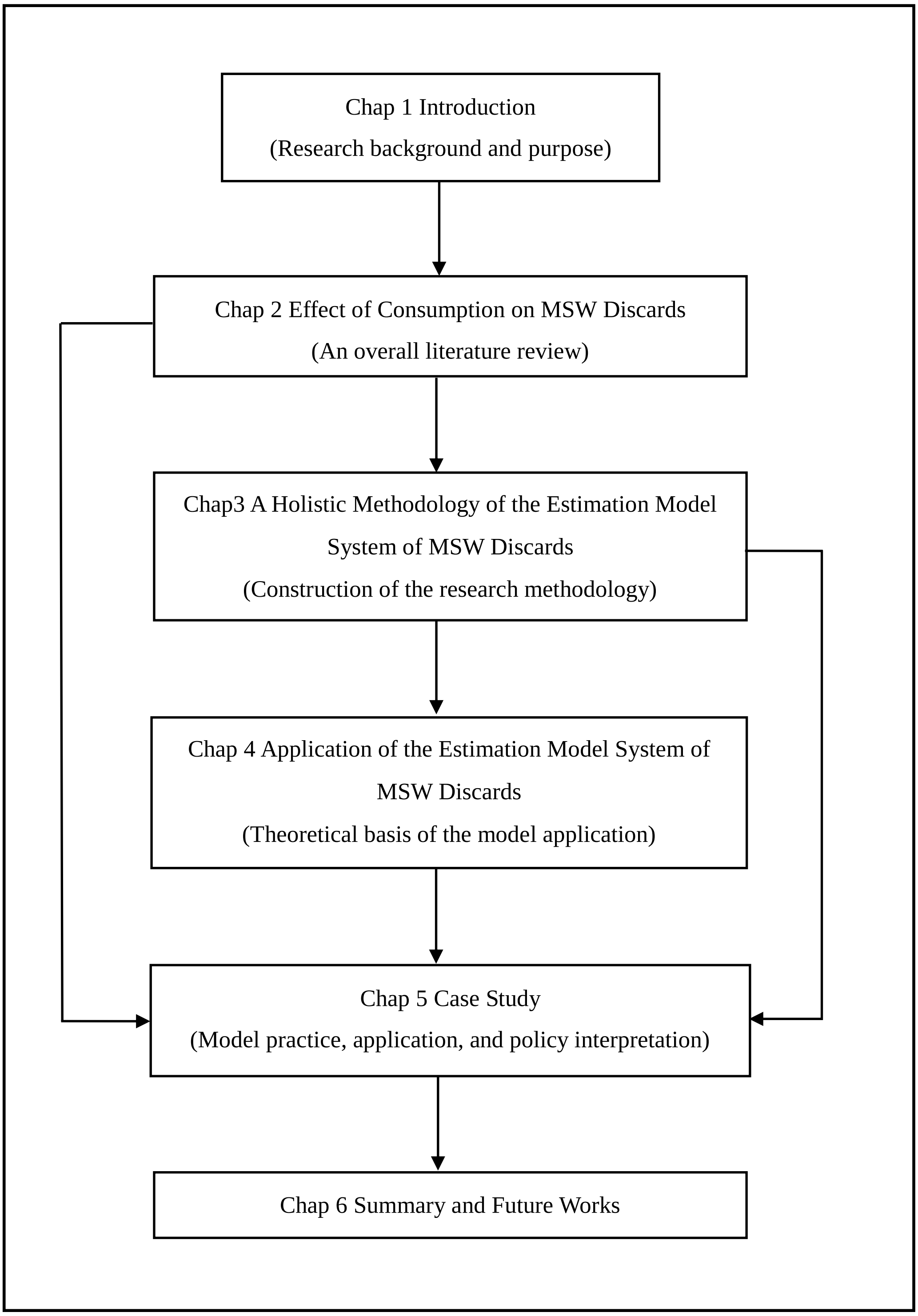

Fig. 1-2 The framework and the linkages among the chapters of this study.

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Chapter 2 Effect of Consumption on MSW Discards

2.1 Lifestyle Changes and Environmental Loadings

Industrialization and urbanization have advanced rapidly all over the world during the last few decades. They have led to great economic growth and alter the phases in life, challenging the traditional believes, values and philosophies of people's life. People appear to have a more convenient and enjoy much more than what they had before in terms of the material phase. However, what has been arouse from by such "rapid" changes, from the perspective of the whole history of the human being, is still a complex problem for the scientists to find the answers.

Namely, the rapid changes in lifestyle have been emphasized by the environmental and sociological studies. The lifestyle analysis (previous called "strata analysis" in social structure analysis) has been applied in disciplines involving sociological phenomena (Duchin, 1998; Contoyannis and Jones, 2004; Ziegenspeck et al., 2004). Previous studies indicated that lifestyle is formed on the basis of the subjective demand or the common goal of an interested group; members within the group may have similar socioeconomic, sociocultural, demographical, and psychological characteristics, e.g. income, household structure, age, time expense, education, race, region, etc. (Duchin, 1998; Diamond, 2003, Bar and Gilg, 2006). That is, one specific lifestyle implies similar life patterns or activities of a specific group with similar attributes over a specific period. Ziegenspeck et al. (2004) further indicated that the "expressive behavior" (including leisure time behavior, clothes style, interior furnishing, and interactive behavior) leads the modern lifestyle.

Even, the consumption, which is revealed by the consumer's behavior, reflects the main aspects of the contemporary lifestyle, provides comprehensive records of the society, and thus well represents the lifestyle in a society. In this study the consumer's behavior refers to the consumer's preferences among different commodities from a monetary perspective, i.e., how a specific group of individuals spend their consumption expenditure on various categories and subcategories of commodities during a specific period. Hence, the consumer's behavior is dominated by the attributes of people's lifestyle. However, the consumer's behavior regarding time expenses is beyond the scope of this study. From the perspective of sustainable development, it is important to expand the discussion from lifestyle changes to the promotion of sustainable lifestyle, and concretely to the promotion of sustainable consumption.

More and more recent studies have attempted to study the relationship between environmental loads and the consumer's behavior regarding the changes in lifestyle. Lintott (1998) advocated that current lifestyle and consumerism in rich economies should be modified by reducing per capita consumption on unnecessary items while consumption should be developed in keeping with sustainable welfare. By using the household expenditure data, Jackson and Marks (1999) conducted one sustainable indicator (the index of sustainable economic welfare, ISEW) for UK to examine the relationship among monetary welfare, sustainable welfare, and the human needs. Noorman (1999) proposed a "Household Metabolism" evaluation system analyzing the household's consumption and its environmental impacts. Jalas (2002) defined the sustainable lifestyle as "a dynamic pattern of consumption of activities in which the related materials use is stable", and the sustainability of the household's consumption was evaluated through a time use approach. Spangenberg and Lorek (2002) performed a consumer cluster analysis based on a SNA-like physical input-output-table; their results suggested that household consumption in terms of the "housing", "eating", and "mobility" activities lead to major environmental threatening in Germany. Rood et al. (2003) utilized a structured model to project the future changes in energy requirement under different consumption scenarios. Gilg et al. (2005) suggested that green consumption can be examined from three perspectives: environmental values and concern, socio-demographic factors, and psychological factors; concrete green-buying actions for households were proposed by conducting a public survey based on the three aspects. Schor (2005) claimed that environmental problems are resulted from the excess consumption driven by falling goods prices.

In the context of waste management, Kanamori and Matsuoka (2006) developed an integrated estimation system for some kinds of environmental loads based on Japanese household consumption date via input-output analysis and econometric modeling; their results suggested that the household's type and size would affect household's consumption behavior and the generation of environmental loads. Nansai et al. (2008) applied the input-output model along with the linear optimization method to find the optimal level of Japanese household expenditure achieving a minimized level of several environmental loads under the assumed scenarios. Fujiwara et al. (2007) developed a model framework analyzing the consumer's behavior and subsequently estimating the quantity of food waste generation in Japan based on the household expenditure data. Moreover, Weng et al. (2008) quantified the relationship among the individual's consumption expenditure, municipal solid waste (MSW) policy measures, and MSW discards in terms of waste fractions in Taiwan by a simultaneous equation system model. Here, the MSW discards is defined as the portion of MSW generation that will be regularly collected and treated by the local municipalities.

As earlier discussed, most environmental problems are resulted from the unsustainable pattern of consumption. However, how should we think of the sustainable consumption? From the viewpoint of the consumption side, a sustainable pattern of consumption should reduce the excess expenditures on the commodities that are not really in need, so that the efficiency of the material utilization could be improved, and eventually the amount of the MSW discards would be reduced. Alternatively, a sustainable consumption should push against the production side, that is, the consumers should force the firms to produce eco-designed products, which designates those are made during the environmental-friendly processes.

Besides, the outcomes of above-mentioned studies have quantitatively or qualitatively proved that the consumer's behavior driven by people's lifestyle brings about the environmental loads, and there is a crucial need to reduce unnecessary consumption, especially for rich economies. However, in order to re-examine the current pattern of consumption, it is required to examine the consumer's behavior and quantify the excess consumption (Lintott, 1998; Schor, 2005). Thus, the first objective of this study is to develop a methodology analyzing the individual's consumption expenditure by using econometric model so that the consumer's preference can be revealed. With regard to the model application, the consumer's behavior model is coupled with the estimation model of the MSW discards and its implication on the design and planning of MSW management system, so that a successive modeling can be achieved.

2.2 Influential Factors of MSW Discards

Many studies have indicated influencing factors of an individual's MSW generation, such as the economic factors, changes in lifestyle, and the governmental policy interventions (Chang and Lin, 1997; Daskalopoulos et al., 1998; Chen and Chang, 2000; Navarro-Esbrí et al., 2002; Dyson and Chang, 2005; Kanamori and Matsuoka, 2006; UNEP, 2006; Bandara et al., 2007; Fujiwara et al., 2007; Beigl et al., 2008). According to their thoughts, the relationships among potential factors of MSW generation/discards are briefly demonstrated by Fig. 2-1. Actually, the factors are interactively linked with each other; both forward and backward influences may coexist within the factors.

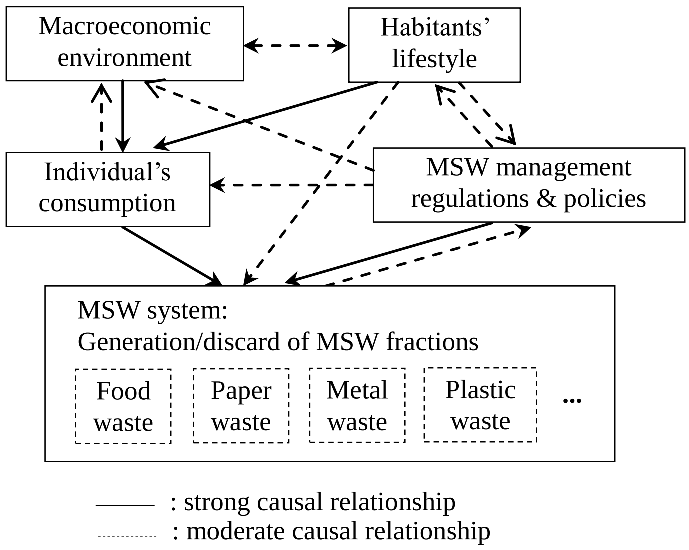

Fig. 2-1 The potential driving factors of MSW generation/discards.

Moreover, some studies also proposed "dematerialization", "slower consumption", and "ecological modernisation" as the solutions for reducing waste generation resulted from the unsustainable lifestyle (Sun, 2003; Ayres and van den Burgh, 2005; Cooper, 2005; Kander, 2005; Jänicke, 2008). The first concept, "dematerialization", attempts to facilitate the unsustainable pattern of consumption and production by reducing excess consumption from the consumption side, and by minimizing the environmental loads from the production side. “Slower consumption” follows similar idea and strengths the life-span of the commodities within the household. On the other hand, “ecological modernisation” tries to improve the performances of environmental policy measures by emphasizing the effect of the technology innovation and its diffusion. In keeping with these concepts, more and more environmental-friendly policy measures are implemented.

2.3 Established Models of MSW Generation

A large body of study is found in literature focusing on the relationship between consumption of commodities and MSW generation, however, seldom with quantification of waste fractions. Many statistical techniques have been developed for estimating and forecasting solid waste generation for different purposes (Chang and Lin, 1997; Daskalopoulos et al., 1998; Chen and Chang, 2000; Navarro-Esbrí et al., 2002; Dyson and Chang, 2005; Heijungs and Suh, 2006; Kanamori and Matsuoka, 2006; Beigl et al., 2008; Chao, 2008; Nansai et al., 2008). Regression method and its extended algorithms are the most common analytical approaches quantifying per capita amount of MSW generation. Single-equation regression analysis is often applied to define the relationship among MSW generation and potential influencing factors. The coefficient of one explanatory variable designates its marginal impact on the explained variable in the equation, making the relation among variables explicit. The explanatory variables are usually economic indices, including the individual’s attributes and his/her income level, often using GDP as an indicator (Beigl et al., 2008). Instead of GDP, Daskalopoulos et al. (1998) adopted the “related total consumer expenditure”, the summation of the individual’s consumption expenditures on “food & drink”, “clothing & footwear”, “furniture & floor covering”, and “books, papers & magazines”, as the explanatory variable in the form of polynomial relationship estimating MSW generation for waste fractions in the United States and United Kingdom on a country level.

However, for every fraction, the form of polynomial remains the same with changes only in the parameters, limiting the interpretation of effect of consumption expenditure on MSW generation. In addition, Bandara et al. (2007) developed single-equation regressions to express the relationship between economic factors and MSW generation in terms of MSW fractions. The results indicated that the income level and the household attributes affect MSW generation in light of changes in lifestyle.

Moreover, time series analysis (TSA) is also widely adopted as an analytical tool since it is based on quantifying the past trend. As for single-variable TSA model, the autoregressive and moving average terms of the dependent variable itself are appropriate to be used as the explanatory variables while constructing the quantification model. Chang and Lin (1997) developed an integrated autoregressive moving average (ARIMA) model to evaluate the effect of recycling policy on MSW generation on a county level by using the monthly data. Also, Navarro-Esbrí et al. (2002) conducted a seasonal ARIMA modeling on a city level to estimate the amount of MSW generation on the basis of daily and monthly data. Furthermore, Chao (2008) built an ARIMA modeling accounting for the policy intervention of the "Keep Trash Off the Ground" measure on a city level, identifying the effectiveness of the policy measure in three major metropolitan areas in Taiwan. As for newly developed techniques, Chen and Chang (2000) considered the poor availability and high uncertainty of MSW data and developed a single-variable grey fuzzy dynamic model on a city level, incorporating advanced TSA technique and being capable of estimating MSW generation even with very limited samples (less than 10). In addition, Chang (2008) applied the autoregressive model with exogenous input (ARX) technique to explore the effect of the lagged influence on the dependent variable as well as other economic variables, and launched multiple-equation regressions by using the SES model to project the generation of waste scraps.

Input-output analysis (IOA) is used as a useful approach for studying the interaction between the economic sectors and MSW generation. Nakamura and Kondo (2002) developed a waste input-output (WIO) modeling approach to analyze the interaction between goods and waste so as to simulate the possible impact of the policy changes on waste management in light of the life-cycle assessment. Kanamori and Matsuoka (2006) developed an integrated estimation system for the environmental loads based on the household consumption in Japan using IOA and regression models; their results suggested that the household's type and size would affect household's consumption behavior and the generation of environmental loads. Nansai et al. (2008) coupled the input-output model with the linear optimization method to quantify the impacts of Japanese household expenditure on several kinds of environmental loads (including the amount of final disposal in terms of waste management) meeting the minimum level under the assumed scenarios.

With the emergence of system dynamics approach, considered to be superior to define casual relationships, Dyson and Chang (2005) established a MSW prediction model on a city level by using population and personal income as independent variables. Besides, Chaerul et al. (2008) applied the system dynamics to establish a comprehensive casual loop diagram among the factors which influence the hospital management system.

From the outcomes of the empirical studies of the abovementioned approaches, in fact, various kinds of analytical models for MSW have their own advantages according to the purpose of study and quality of database. However, some of the major limitations could be enumerated as follows:

- Most of the studies attempt to correlate the quantity of waste with some of the logically relevant economic indicators without dealing with the waste generation phenomenon.
- Hardly any studies provide analysis for MSW discards as well as individual MSW fraction.
- In case of regression analysis, only few empirical studies quantified the overall relationship between MSW generation and consumption behavior.
- Some assumptions of the estimation method in regression analysis, such as the multicollinearity among the explanatory variables, should be examined in detail for their influence on the outcomes in the regression model.
- Single-equation regression model is difficult to account for the cross-equation

correlations, so that bias may exist in multi-equation regression model.

- In IOA model, the waste generation coefficients in terms of waste fraction are necessary in the estimation while such data is neither available nor credible for most regions; uncertainty may exist to a certain extent in the analysis.
- As for the traditional single-variable TSA model, it is difficult to account for various influencing factors simultaneously. But the ARX model may deal with such deficiency.
- As for system dynamics method, although casual relationships among the factors can be clarified definitely, quantitative simulation is still being improved.

It has been observed that quantitative analysis of MSW generation based on mere statistical relationship always has limitations due to the assumptions made while deciding the function form and specification of independent variables. Instead, it would be appropriate to understand the process of MSW generation, or more precisely, the conversion process from commodities to waste before quantifying this process so that ultimately the MSW generation phenomenon could be described precisely and accurately. In keeping with this thought, a modeling attempt is made and described in the following sections.

2.4 Material Conversion during the Consumption Process

Several characteristics are associated with the conversion process from commodities to waste: any kind of commodity could get disaggregated into several categories of waste. For example, canned food can generate two types of waste (food waste and metal waste) during the consumption. Thus, simultaneously considering the correspondence between the categories of commodities and the waste discards by composition is required. Secondly, each commodity has its own retention time in a household. The duration of the commodities in use depends on their characteristics (durable or non-durable). Therefore, the MSW discards is a highly dynamic and uncertain process. Thirdly, in the utilization process of the commodities, a part of the weight of commodities may be lost or added, and afterward be converted into waste. For example, moisture in similar kinds of waste usually changes spatially and temporally; besides, the residual of food usually decreases to a significant extent. These principles construct the main concept that waste comprises discarded commodities that are broken or useless after being used.

In accordance to the above-proposed concept, Dijkema et al. (2000) asserted that waste would be qualified if a substance or an object is not used to its full potential. Cooper (2005) also proposed the concept of "slower consumption", which advocates prolonging the life-span of the commodities in use, so that the utilization efficiencies of materials can be improved and MSW generation rate may be reduced. Based on the above-mentioned concepts, MSW generation is highly related to the lifestyle patterns as well as the consumer's behavior. However, all the potential factors mentioned in the conversion process enlarge the uncertainty in developing a quantitative modeling.

It seems tangible to use the amounts of commodities reflecting MSW generation/discards, but in fact such data is rarely available. Empirical studies use the income level (e.g. the gross domestic product, GDP) to represent the consumption level, which is an influencing factor of MSW generation (UNEP, 2004; Dyson and Chang, 2005; Beigl et al., 2008); however, a proportion of an individual's income may be deposited for future use, or be used for investing. In this sense, the income level is indirectly associated with the amount of the MSW generation/discards. Instead, the consumption expenditure is a direct indicator in terms of the waste conversion process. In the majority of the countries, per capita household expenditure is also available. Furthermore, this concept is also consistent with the idea proposed by Daskalopoulos et al. (1998) and UNEP (2006). In addition, the official records of MSW generation or discards are often quite short; on the other hand, most countries have abundant data for the socioeconomic indices including the household expenditure.

Modeling the MSW discards on the basis of expenditure data would be very useful and easy to be performed, and it could provide both forecast and backcast estimates by using the target values of the national planning and historical records of the required parameters, respectively. The backcast estimates of the MSW discards rate can provide a primary image of what happened in the past, so that the current MSW management system can be examined and facilitated; on the other hand, the forecasts support the design of future MSW management system as well as the policy making.

A conceptual casual effect of the individual's consumption expenditure on MSW generation/discards can be represented as Fig. 2-2.

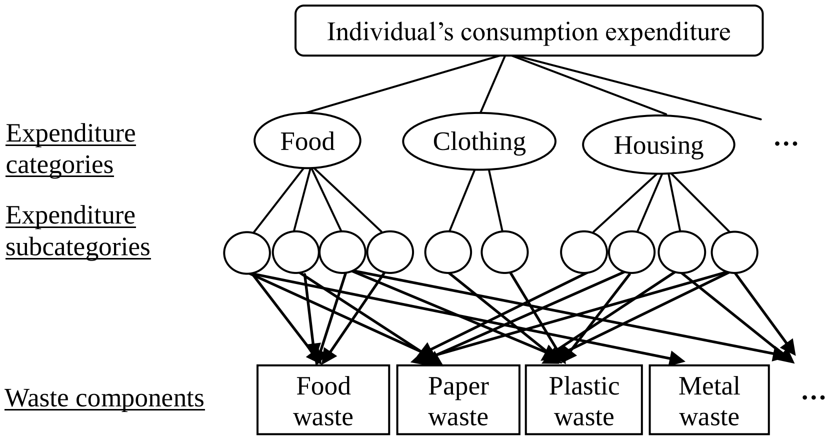

Fig. 2-2 Conceptual casual relationships of individual's consumption expenditure on MSW waste

As the environmental concern of the public rises, the recycling activities play an important role in the MSW discards. Hence it is important to include the policy effects into the modeling work. To sum up, this study focuses on quantifying the effects of consumption factors and MSW management policies on the MSW discards in term of waste fractions, simultaneously, on the basis of the waste conversion process during the consumption. Based on such quantitative modeling, concrete strategies for facilitating current unsustainable consumption pattern can be proposed and tested so as to promote a low waste society.

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Chapter 3 A Holistic Methodology of the Estimation Model System of MSW Discards

In constructing the quantitative modeling, econometric models serve as powerful tools and are widely applied. As earlier discussed in Chapter 2.4, regression model (one basic approach in the econometric models) appears to be superior to clarify the relationship among the influential factors of MSW in light of the waste conversion processes during the consumption. Meanwhile, this study makes a particular attempt to analyze the consumer's behavior in light of the changes in lifestyle so as to achieve the study of purpose mentioned in Chapter 1.

The overall estimation model system is constructed by assuming that the MSW discards is primarily influenced by the consumption factor as well as the governmental policy measures. Hence, the integrated model system simulates the MSW discards in terms of waste fraction based on the consumption expenditure and the MSW policy interventions. It comprises (1) the consumption forecasting model, (2) the consumer's behavior model, and (3) the MSW discard model.

By using the econometric techniques, the integrated model system started at developing the consumption forecasting model simulating the individual's overall consumption expenditure based on the macroeconomic and socioeconomic indicators with a single-equation regression model. Subsequently, the consumer's behavior model, analyzing the consumer's preferences in terms of the lifestyle changes, is to be a two-layer structure based on the hierarchical analysis of per capita consumption expenditure, comprising of the linear expenditure system (LES) model and the multinomial logit (MNL) model. Consequently, the MSW discard model, representing the conversion process from commodities into waste during the consumption, is to be established via the multi-equation regression model (the simultaneous equation system (SES) model). The modeling framework can be presented as Fig. 3-1.

Chapter 3 focuses on presenting the methodology of the abovementioned models as well as their theoretical basis.

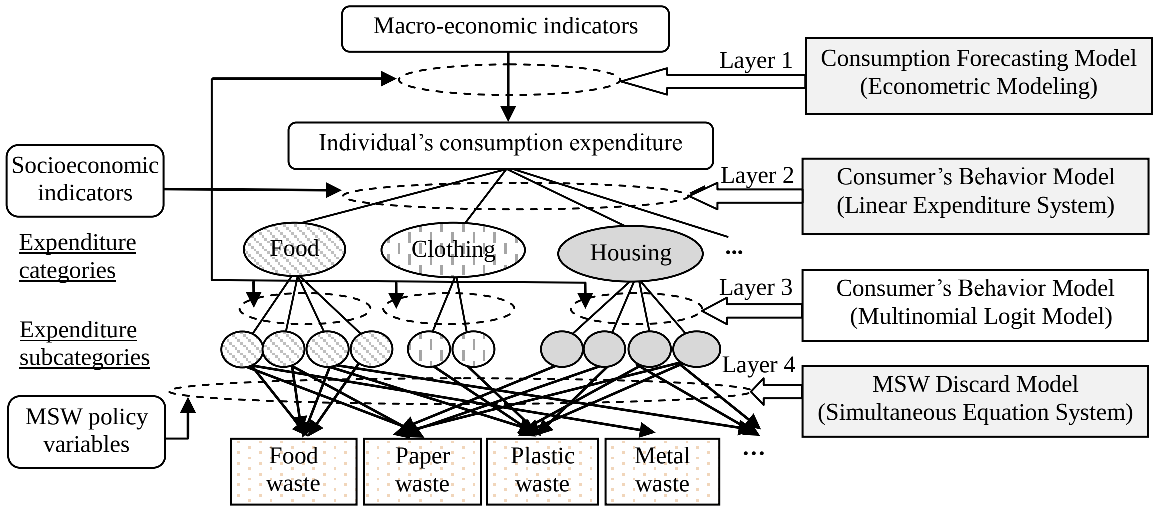

Fig. 3-1 Model flow diagram of the integrated model system of MSW discards.

3.1 Basics of Econometric Models (Pindyck and Rubinfeld, 1998; Greene, 2002)

Econometrics model designates the modes analyzing the causal relationship on a specific economic or social phenomenon based on the relevant economic theories. Various kinds of regression methods are often applied in developing econometric models. The econometric model can be classified into different types depending on its scale of simulation period and spatial wideness. As for the spatial scale, an econometric model can be classified as a local-scale model on a city or district level, a meso-scale model on a prefecture or county level, or a regional-scale model on a national or multi-nation level. From the perspective of time scale, an econometric model can be generally classified as into three types: a short-term simulation (e.g. less than five years), a mid-term simulation (e.g. from five to ten years), or a long-term simulation (e.g. more than ten years), depending on their study duration of interest. However, a convincing econometric model relies on the availability and credibility of information.

3.1.1 Single-equations Modeling

3.1.1.1 Introduction of Single-equation Modeling

In econometric modeling, one equation can be used to describe a behavior or a phenomenon in a statistical way. The objectives of study interest are the explained (or dependent) variables simulating by the explanatory (or independent) variables which have strong causal relationships with the explained variables in the equations. The general form of single-equation model can be represented as follows:

$$\boldsymbol{y} = \boldsymbol{f}(\boldsymbol{x_m}^{\mathrm{T}}\boldsymbol{\beta_m}) + \boldsymbol{\varepsilon} \tag{3-1}$$

where $\boldsymbol{y}$ denotes the row vector of explained variable; $\boldsymbol{x_m}$ is a column vector of explanatory variables related to $\boldsymbol{y}$; $\boldsymbol{f}(\cdot)$ is the function of $\boldsymbol{x_m}$ on y; $\boldsymbol{\beta_m}$ is the column vectors of the parameters; $\boldsymbol{\varepsilon}$ denotes the row vector of the error term (or residual), reflecting the effects of unobserved variables. The estimators of parameters (coefficients) represent the marginal effects of the variables on the explained variable in the equations, that is, the change of the explained variable after the change by 1 unit of the explanatory variable. Thus the marginal impacts of the explanatory variables on the explained variable in each equation will be clarified provided that the estimators of the parameters.

If the linear function is adopted, Eq. (3-1) can be represented as follows:

$$\boldsymbol{y} = \boldsymbol{\alpha} + \boldsymbol{x_m}^{\mathrm{T}}\boldsymbol{\beta_m} + \boldsymbol{\varepsilon} \tag{3-2}$$

Additionally, $\boldsymbol{\alpha}$ represents the row vector of constant term.

In the econometric analysis, the causal relationships among the explained and explanatory variables are quantitatively defined by the parameters (or coefficients) of the explanatory variables. Thus, the credibility of the parameters is of particular importance.

3.1.1.2 Model Estimation and Diagnose

The estimation of an econometric model is to find the estimators of parameters with statistical significance and to minimize the variances between the estimates and true values of the explained variable. The single-equation models can be solved by the ordinary least-squares (OLS) method or generalized least-squares (GLS) method if heteroscedasticity error terms exist in the OLS estimation. The parameters from OLS are usually biased and inefficient. However, it is a powerful method in the small-sample modeling and easy to be operated.

The t test and F test are used to judge the significance of the estimators for the parameters. In addition, adjusted coefficient of determination (adjusted R^2) is used as the measurement of the "goodness of fit" for each equation if the sample size is not large (e.g. less than 30); otherwise, R^2 will be evaluated. The mean absolute percent error (MAPE) is used to evaluate the bias between the estimates and the true values of the endogenous variables. MAPE is calculated as follows:

$$\text{MAPE} = \left(\frac{1}{N} \sum_{s=1}^{N} \frac{\left| \hat{Y}_s - Y_s \right|}{Y_s} \right) \times 100\% \tag{3-3}$$

where Y_s and $\hat{Y}_s$ are the original series and the model fitting values, respectively; N is the length of the series.

Statistically significant parameters of the explanatory variables in econometric modeling imply that the variables have significant impacts on the explained variable. In regression techniques, the estimators for the parameters are expected to be the best linear unbiased estimators (BLUE), indicating the following properties should be obeyed (Greene, 2002).

□ Lack of bias (Unbiased): it implies the expectation of estimator of parameter minus the parameter would equal to zero, i.e., $E(\hat{\beta}) - \beta = 0$.

□ Efficiency: it means the square of the estimated error, $\hat{\varepsilon}^2$, would decrease as the sample size increases.

□ Consistency: the probability limit of $\hat{\boldsymbol{\beta}}$ would approach to $\boldsymbol{\beta}$ as the sample size increased.

□ Minimum variance: that means the expectation of the square of estimated error of the parameter, $E(\hat{\beta} - \beta)^2$, would be minimized.

Moreover, some statistical indices and tests can be launched to diagnose the validity of the regression results. The Lagrange multiplier (LM) test in terms of Breusch-Pagan test, for example, is to diagnose the heteroscedasticity within the error terms in each equation, and smaller values of LM statistic implies the insignificance of heteroscedasticity error terms (Bronwyn and Clint, 2005b). The variance inflation factor (VIF) can be used to test the existence of multicollinearity among explanatory variables in each equation (e.g. less than 10). Alternatively, the significance of the estimators can serve as an indicator on evaluating the multicollinearity problem as well. If most insignificant parameters and high R^2 (or adjusted R^2) appear in the equation simultaneously, the multicollinearuty problem may arise. The Dubin-Waston (DW) statistic is to evaluate the degree of serial correlation among the residuals of each observation for each equation (e.g. close to 2); however, if the lag term of the explained variable is used as a explanatory variable in the equation, the Durbin-h statistic would be used. If one test is violated, modification of the modeling work should be carried out to ensure the validity of the estimators. However, if the heteroscedasticity is not severe in a case with less than 250 samples, the mild heteroscedasticity does not affect the credibility of the model (Long and Ervin, 2000).

In econometric analysis, the full time period can be classified into four types for the model development and application (Pindyck and Rubinfeld, 1998). The first is the estimation period, in which the model is developed; following by the ex-post forecast period, implying the period from the end of estimation period to the end of historical records; the third is the ex-ante forecast period, which means the future times; the last is the backcast period, indicating the time before the estimation period. The validity of the model can be tested by evaluating the MAPE during the estimation period, and the forecasting accuracy of the model is tested during the ex-post forecast period. A lower value of MAPE suggests that estimates of the model are accurate and convincing.

The interpretation of a single-equation model is explicit. The effects of unobserved variables are considered in the residual of the equation. But if the residuals of different equations are related, the OLS estimation may be biased. In such a case, the respective model has to be modified in terms of the BLUE properties; otherwise, the cross-equation correlations should be accounted for by using the simultaneous equation system (SES) in the multi-equations modeling to get the BLU estimators of parameters.

3.1.2 Multi-equations Modeling

3.1.2.1 Introduction of Multi-equation Modeling

For most quantitative studies, usually several relevant variables are of interest in studying a phenomena or a system, e.g., simulating an atmospheric phenomena or constructing a macroeconomic modeling system. The model developers may establish multi-equations to study their theme of interest. In such cases, the explained variables may be intrinsically correlated so that the interactions among the explained variables should be taken into consideration simultaneously. Such models are so called the simultaneous equation system (SES).

The SES model is considered as a set of functions of system, comprising of the behavior equations and the identity equations. The explained variables in the equation system are endogenous, implying they are intrinsically correlated and should be decided simultaneously. On the other hand, the variables, which are determined outside the equation system, are defined as exogenous variables in the SES model. Besides, the lagged endogenous variables, which are determined within the equation system, are called as predetermined variables. The exogenous variables and the lagged endogenous variables commonly serve as explanatory variables in the SES model. Since all the parameters of variables in the equation system are estimated simultaneously, the SES model may account for the interaction among endogenous variables (Pindyck and Rubinfeld, 1998). Moreover, the outcomes of the SES model can be straightforwardly interpreted like the single-equation regression model. Basic steps of developing an SES model are described in Fig. 3.2.

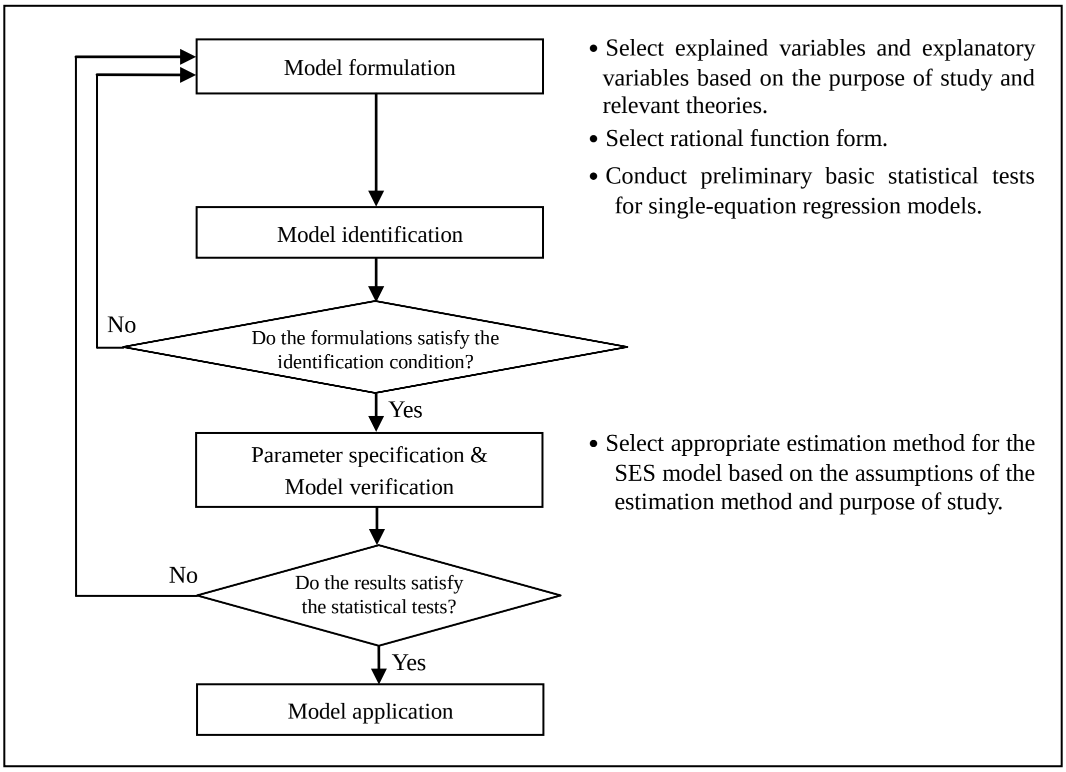

Fig. 3-2 The basic steps for developing a SES model.

3.1.2.2 Identification and Estimation of Simultaneous Equation System

The identification problem is of prime importance in developing a SES model. Only the identified or over-identified model can be solved. The "order condition" is often used as criteria to test the identification (Pindyck and Rubinfeld, 1998). Let G denotes the number of all endogenous variables in the SES model; G^* the number of the endogenous variables within the SES model, but not in the current equation; K the number of all the exogenous variables in the SES model; K^* the number of exogenous variables within the SES model, but not in the current equation. If $G^* + K^* > G - 1$, the SES model is over-identified, more than one estimate is possible for some parameters; if $G^* + K^* = G - 1$, the SES model is exactly identified, and only one set of solution will be obtained; if $G^* + K^* < G - 1$, the SES model is unidentified, so that the SES cannot be solved.

Many estimating methods can be used in solving an equation system, such as the ordinary least squares (OLS) method, the instrument variable (IV) estimation method, the two-stage least squares (2SLS) method, the three-stage least squares (3SLS) method, the full-information maximum likelihood estimation method (FIML), the seemingly unrelated regression (SUR) method, and analytical numerical methods, etc. (Pindyck and Rubinfeld, 1998; Greene, 2002; Bronwyn and Clint, 2005a). Some estimation methods specifically developed for the SES model are briefly introduced in the following:

□ 2SLS method or IV method

2SLS and IV induce a reduced form of the model system by using instrument variables and then solved using OLS method.

□ 3SLS method

3SLS is an extension of 2SLS, involving generalized least-square (GLS) estimation, each of which has firstly estimated by 2SLS. Thus, in some cases, it would degenerate into an OLS one. Consistent and efficient estimators would be obtained (superior to 2SLS). However, 3SLS is sensitive to the deterministic error term.

□ FIML method

The FIML induces the likelihood function to calculate the estimators of parameters. Consistent and efficient estimators would be obtained. But FIML is sensitive to the deterministic error.

□ SUR method

The cross-equation interactions are just considered in the error terms among the equations in SUR model. The SUR method involves generalized least-square (GLS) estimation. Thus, in some cases, it would degenerate into an OLS one.

□ Numerical methods

Some numerical methods, such as Newton's method or its extended algorithms, can estimate the parameters by minimizing the variances of the equations. This method is appropriate in the system composing of nonlinear equations with large sample size and large number of equations.

Considering the BLUE property, the empirical experiment results show that 2SLS, 3SLS, FIML, and SUR yield consistent and efficient estimators. Furthermore, the estimators of OLS are inconsistent and inefficient for most cases. Besides, 3SLS, FIML, and SUR are better than 2SLS. But the SES models are more complex and require more model development techniques as well as large-sample datasets. Even, Kiviet and Phillips (1996) argued that bias exists in the equation system solved by OLS method if explained variables in the equation system are associated with each other. Furthermore, the empirical results of developing cost functions for the landfill facilities in Taiwan (Weng and Chang, 2001) showed that the significance of the SES model is better than the results from equations solved independently by the OLS method. Besides, comparing various estimating methods in their SES model, the results using the SUR method is the most significant. Similar conclusion was also suggested in the development of house price equation in terms of industrial pollution (Hanna, 2007) as well as the scrap tire forecasting in Taiwan (Chang, 2008). However, the SES model and its estimation require large sample to support, so that the SES model may not significantly superior to single-equation models in the small sample-size estimation.

3.2 Influential Factors on the Consumer's behavior

In the earlier section, the methodologies of econometric modeling are discussed. Before building a model, influential factors in terms of the variable of interest should be exploited qualitatively. In accordance with this concept, this section attempts to identify the affecting factors on the individual's consumption so that subsequently these factors can serve as the explanatory variables in the development of the quantitative models in terms of the consumer's behavior.

Primarily, some factors may affect the consumer's behavior: the personal income level, his/her personal attributes, the socioeconomic factor, demographic indices, as well as the cultural and psychological factors (Sood and Nasu, 1995; Hildenbrand and Kneip, 1999; Bihagen and Katz-Gerro, 2000; Carroll, 2001; East and Hogg, 2000; Kokkinaki, 2000; Roos et al., 2001; Altonji et al., 2002; Liou et al., 2002; Wilk, 2002)

(1) Personal income level

The consumer's income level in terms of the wage and working hours is considered as the most important factor on the individual's consumption (Carroll, 2001; Altonji et al., 2002). Usually, the income level can be represented by the per capita gross domestic production (GDP) or per capita disposable income. Despite the personal income level, alternatively, the per capita consumption expenditure can be more directly reflect the consumer's behavior.

(2) The consumers' attributes

Most of the consumer's personal characteristics are related to his/her preferences on consumption in terms of the psychological perspective, e.g., the education level, career, household attributes, region (also the nationality), race, gender, religiosity, etc. (Sood and Nasu, 1995) The consumer's education level and career, actually, are correlated, and these two factors are strongly associated with the structure of time use. Meanwhile, people in the same region or belonging to the same race may have similar pattern of consumption. Even, the gender would lead to different types of the consumer's behavior (Bihagen and Katz-Gerro, 2000; Roos et al., 2001).

(3) Socioeconomic factors

Indeed, the national-wide socioeconomic factors affect the individual's income level, his/her consumption level, and his/her preferences on consumption, e.g., the economic growth (growth of GDP), unemployed rate, prices inflation, the inequality of income (Gini coefficient for example), the saving ratio or bank rate, and foreign dollar exchanges rate (Carroll, 2001; Altonji et al., 2002).

Meanwhile, the social and cultural changes of the society alter the consumer's behavior, associated with the extent of urbanization and the development of technology and advertisement, etc. (East and Hogg, 2000; Kokkinaki, 2000; Jim and Chen, 2007). The changes of communication technologies also alter the consumer's behavior in terms of the degree of information diffusion, for example, the popularity of internet (i.e. E-commerce), mobile phone, and cable TV etc. (Sultan, 2002; Olson and Boyer, 2003)

(4) Demographic indices

In recent times, the population structure (especially the ratio of the elders), the individual's life span, as well as the individual's education level in terms of the household attributes, are also influential factors in the determination of the consumption process (Roos et al., 2001; Wilk, 2002).

In the abovementioned discussion, many factors affect the consumer's behavior indeed. However, it seems that limited factors can be used in modeling the consumer's behavior on a national level, mainly the macro socioeconomic indicators as well as the household attributes. Therefore, the following sections would develop the models in accordance with the concepts discussed here.

3.3 Consumption forecasting model

In order to estimate future MSW discards, the consumption forecasting model is introduced to the projection system in this study and serves as the first-layer model for the estimation model system (see Fig. 3-1). Firstly, annual per capita consumption expenditure is estimated by using macro-economic variables and variables associated with the lifestyle changes within the consumption forecasting model.

In the theory of consumption, the per capita consumption expenditure is assumed as a function of his/her income level. However, this process would be affected by the consumption pattern (or habit) of respective consumer in terms of his/her value on managing the money and lifestyle. Based on the discussion in Chapter 3.2, in this study, macro socioeconomic indices and household attributes are induced as influential factors representing the lifestyle on the consumption behavior.

Four hypotheses are widely applied to describe the consumption behavior: the Absolute Income Hypothesis, the Relative Income Hypothesis, the Life-Cycle Hypothesis, and the Permanent Income Hypothesis (Tanaka et al., 1995; Carroll, 2001; Liou et al., 2002).

(1) Absolute Income Hypothesis

Absolute Income Hypothesis, proposed by Keynes (1936), assumes the individual's consumption level is only influenced by his/her current income level. Past consumption pattern would not affect the current consumption behavior. Thus the relationship can be formulated as:

$$c_t = g_1(y_t) \tag{3-4}$$

and

$$0 < \frac{\partial c_t}{\partial y_t}, \ \frac{\partial c_t}{\partial y_t} < \frac{c_t}{y_t} \tag{3-5}$$

where c_t denotes the annual per capital consumption expenditure in year t; y_t is the annual per capita annual income in year t; $g_1(\cdot)$ is the function of y_t on c_t.

The general formulation adopts the linear function, representing as:

$$c_t = \alpha + \beta \times y_t + \varepsilon_t \tag{3-6}$$

where α denotes the autonomous income, and $\alpha > 0$; β designates the marginal propensity to consume (MPC), and the $0 < \beta < 1$; ε_t is the error term.

(2) Relative Income Hypothesis

Relative Income Hypothesis, proposed by Duesenberry (1949), supposes the individual's consumption pattern would affect interactively, implying that the consumption on a level is compared to other individuals and affected by his/her own income level. The relationship can be formulated as follows:

$$\frac{c_{at}}{y_{at}} = \alpha_0 + \alpha_1 \times \frac{\overline{y_t}}{y_{at}} \tag{3-7}$$

where $c_{a,t}$ denotes the consumption expenditure in year t for consumer a; $y_{a,t}$ is the income in year t for consumer a; $\bar{y}_t$ is the average income in year t for all the individuals; $y_{a,p}$ is the highest income that the consumer *m* has obtained.

In addition, the Relative Income Hypothesis argued that the irreversibility exists in the consumption, and the individual's consumption would be affected by not only the current income but his/her peak income (Duesenberry, 1949). Thus, Eq. (3-7) can be further derived as the following equation:

$$\frac{c_t}{y_t} = \alpha_0 + \alpha_1 \times \frac{y_0}{y_t} \tag{3-8}$$

where y_0 denotes the individual's peak income.

Furthermore, in order to reflect the irreversibility of consumption, Eq. (3-8) can be reformulated as follows:

$$c_t = \alpha_0 \times y_t + \alpha_1 \times y_0 + \varepsilon_t \qquad 0 < \alpha_0 < 1,\ 0 < \alpha_1 < 1 \tag{3-9}$$

Assuming that the individual's income grows constantly, the peak income can be represented by the one-year lag of the individual's income. Thus, Eq. (3-9) can be reformulated as:

$$c_t = \alpha_0 \times y_t + \alpha_1 \times y_{t-1} + \varepsilon_t \tag{3-10}$$

(3) Life-cycle Hypothesis

Life-Cycle Hypothesis, proposed by Ando and Modigliani (1957, 1963, 1964), argues that the individual's current consumption is affected not only the current income level but his life-time income level. Thus, the consumer maximizes his/her utility by consumption constraining under the wealth in his life. It can be formulated as follows:

$$c_{a,t} = g_2\,(y_{a,t}, y_{a,e}, \ldots) \tag{3-11}$$

where $c_{a,t}$ is the annual consumption expenditure for person *a* in year *t*; $y_{a,t}$ is the annual income for person *a* in year *t*; $y_{a,e}$ is the aggregate income for person *a* in his/her life; g_2 (·) represents the corresponding consumption function.

(4) Permanent Income Hypothesis

Permanent Income Hypothesis, proposed by Friedman (1957), assumes that the income can be divided into parts: the permanent and transitory income. Suppose that the consumption is associated with the permanent income and other influential factors; besides, the transitory income is expected to have a mean near zero over a long term period and is approximately uncorrelated with the permanent income (Tanaka et al., 1995; Romer, 2002). Based on the assumptions, the current income can be represented as follows:

$$y_t = y_t^{perm} + y_t^{trasn} \tag{3-12}$$

where y_t is the per capita income in year t; y_t^{perm} denotes the permanent income in year t; y_t^{trasn} is the transitory income in year t, and $E(y_t^{trasn}) = 0$.

Based on the abovementioned assumptions, an adaptive expectation permanent income hypothesis consumption function can be expressed as follows (Hadjimatheou, 1987; Tolar, 1997):

$$c_t = \beta_1 \times y_t + \beta_2 \times c_{t-1} + \varepsilon_t \qquad 0 < \beta_1 < 1,\ 0 < \beta_2 < 1 \tag{3-13}$$

In Eq. (3-13), the current consumption would be influenced by the current income level, the past consumption level (representing the individual's consumption habit), and other influential factors, e.g. the current socioeconomic situation.

The consumption forecasting model, thus, can fit with the historical data in an appropriate function form accounting for the abovementioned theories, so that the pattern of the individual's consumption expenditure and its influential factors can be clarified. Meanwhile, structure changes in the behavior of the series should be considered in developing the model. Considering econometric modeling approaches, the forecasting model is established by the single-equation regression model though a SES model may be developed as well if relevant economic behaviors are to be considered simultaneously.

After conducting a reasonable consumption forecasting model, it is critical to analyze the distribution of it among the categories and subcategories of the commodities.

3.4 The Consumer's Behavior Model

After the per capita overall consumption expenditure is analyzed and capable of being forecasted in terms of the lifestyle changes, the per capita consumption expenditure estimated in the previous model is used as the input of the consumer's behavior model, analyzed by two-layer econometric models with regards to the categories and subcategories of the consumption expenditure, hierarchically. The consumer's behavior model aims to analyze the individual's consumption preferences in terms of the lifestyle changes so as to model the distribution of his/her consumption expenditure.

3.4.1 Linear expenditure system

The linear expenditure system (LES) model is adopted in the first layer of consumer’s behavior model to analyze the consumer’s preference among categories of the individual’s expenditure. The LES model, first proposed by Stone, has been applied widely in analyzing the household expenditure (Stone, 1954; Maki, 1983; Narayana and Vani, 2000; Wilhelmsson, 2002; Hudson et al., 2003), and been adjusted into extended forms by Lluch, Merz, and Adams, respectively (Lluch, 1973; Merz, 1983; Adams, 1989). The LES model is an equation system that considers endogenous variables of consumption expenditure fractions. The aggregated per capita consumption expenditure and the socioeconomic indices reflecting the changes in lifestyle serve as exogenous variables. In this way, the LES model can be extended with widely economic application. Moreover, a straightforward interpretation of the LES model enables an advanced simulation of the consumer’s behavior.

In the LES model, the individual spends to maximize his/her utility (based on the Stone-Geary utility function) with his/her budget constraint. The Stone-Geary utility function is defined as (Stone, 1954):

$$U = \sum_i \alpha_i \log\left(q_{i,t} - q_{i,t}'\right) \tag{3-14}$$

where $q_{i,t}$ is the quantity of commodities or services consumed from the i_{th} expenditure category in year t, including food, clothing, housing, household appliance, medicines & medical care, transportation & communication, amusement & education, and miscellaneous items; $q_{i,t}'$ means the subsistence quantity (or minimum quantity required) of commodities or services of the i_{th} category in year t; α_i is interpreted as the marginal budget share of each expenditure category with a constraint $\sum_i \alpha_i = 1$.

The LES model assumes that a consumer’s demand is divided into the subsistence level and the non-subsistence level of consumption (requirement exceeding the basic need), which implies that the individuals will choose what they desire to have after deducting the subsistence value from their consumption expenditure. The basic form of the LES model can be represented as:

$$p_{i,t}q_{i,t} = p_i q_i' + \alpha_i \left(c_t - \sum_j p_{j,t} q_{j,t}' \right) \qquad i = 1,\ldots, I; j = 1,\ldots, I \tag{3-15}$$

where $p_{i,t}$ denotes the average price of goods in the i_{th} category in year t at the base year prices; C_t represents the individual's overall expenditure in year t. By Eq. (3-15), the marginal budget share depicts what would be consumed to a certain extent for people to satisfy their basic needs and wants, delicately describing the consumer's preference.

Besides, this study assumes that the subsistence quantity under each expenditure category is influenced by the socioeconomic situation involving the changes in lifestyle, such as economic factors and household attributes. That is

$$q_{i,t}' = b_i + \sum_k b_{ik} r_{k,t} \tag{3-16}$$

where $r_{k,t}$ denotes socioeconomic variables associated with the changes in lifestyle; b_i and b_{ik} are the parameters.

Then Eq. (3-15) can be reformulated as:

$$\begin{aligned} c_{i,t} &= p_{i,t}\left(b_i + \sum_k b_{ik} r_{k.t} \right) + \alpha_i \left[C_t - \sum_j p_{j,t}\left(b_j + \sum_k b_{jk} r_{k,t} \right) \right] \\ &= \left(p_{i,t} b_i + \sum_k p_i b_{ik} r_{k,t} \right) + \alpha_i \left[C_t - \sum_j \left(p_{j,} b_j + \sum_k p_{j,t} b_{jk} r_{k,t} \right) \right] \\ &= \left((b_i') + \sum_k (b_{ik}') r_{k,t} \right) + \alpha_i \left[C_t - \sum_j \left((b_j') + \sum_k (b_{jk}') r_{k,t} \right) \right] \end{aligned} \tag{3-17}$$

where $c_{i,t}$ represents an individual's expenditure by category in year t, i.e., $c_{i,t} = p_{i,t} \times q_{i,t}$.

By such articulation, Eq. (3-17) can be solved using nonlinear three-stage least squares (3SLS) method (Maki et al., 1997). After estimating the consumption expenditure on the categories, a choice-experiment model is established in order to model the distribution of each consumption expenditure category into its respective subcategories.

3.4.2 Multinomial logit model

At this stage, a general type of discrete choice-experiment model, the multinomial logit (MNL) model, is applied to simulate the distribution of an individual's expenditure under one category into its subcategories. The MNL model is powerful at analyzing the choice experiment with multiple choice sets, and provides straightforward interpretation with appropriate explanatory variables (McFadden and Train, 2000; von Haefen, 2003). Recently the MNL model has been applied in some environmental studies for simulating choice-selecting process (Iragüen and de Dios Ortúzar, 2004; Wattage et al., 2005; Nakatani et al., 2007). Based on maximizing the random utility function, the MNL model claims that individuals will make the choice with the maximum utility. The basic form of random utility function with T choosers and J choice sets is as follows:

$$\boldsymbol{U}_{tj} = \boldsymbol{v}_t + \boldsymbol{X}_i^T \boldsymbol{\zeta}_i + \boldsymbol{e}_{tj} \qquad t = 1,\ldots, T\,;\, j = 1,\ldots, J \tag{3-18}$$

where $\boldsymbol{U}_{tj}$ denotes column vector of the latent (or unobservable) utility value, and the latent utility for each chooser will be maximized by selecting the most appropriate choice set; $\boldsymbol{x}_i$ is a column vector of the explanatory variables; $\boldsymbol{v}_t$ and $\boldsymbol{\zeta}_i$ are column vectors of the parameters; moreover, the error term, $\boldsymbol{e}_{tj}$, in each utility function has a generalized extreme value distribution (Bronwyn and Clint, 2005).

The explanatory variables in the MNL model are the chooser-specific regressors; that is, the explanatory variables are only related to the characteristics of the individual chooser. In this study, the "chooser" infers the aggregate consumption behavior of the citizens in each sampling year. Thus, the MNL model is applicable in the case study. Performing the MNL model, the probability for consumption expenditure distributed from category i into its subcategories, $prob(\psi_{ij,t})$, can be specified as follows:

$$prob(\psi_{ij,t}) = \frac{\boldsymbol{c}_{ij,t}}{\sum_h \boldsymbol{c}_{ih,t}} = \frac{exp(\boldsymbol{x}_{i,t}{}^{\mathrm{T}}\boldsymbol{\beta}_{ij})}{\sum_h exp(\boldsymbol{x}_{i,t}{}^{\mathrm{T}}\boldsymbol{\beta}_{ih})} \qquad \forall\, i, j, t, h; \tag{3-19}$$

where $c_{ij,t}$ denotes the consumption expenditure of the j_{th} subcategory in the i_{th} category in year t; $\boldsymbol{x}_i$ is a column vector of the explanatory variables that reflect socioeconomic situations such as household's attributes for category i; $\boldsymbol{\beta}_{ij}$ represents the column vector of the parameters that corresponds to the explanatory variables.

An important assumption of the MNL model is the independence of irrelevant alternatives (IIA), that is, the rate of probabilities between any two choice options is independent in the choice set. In this study, since the choice sets refer to the subcategories, in which an individual's expenditure is distributed, the characteristic of one subcategory of expenditure is clearly different from another thus obeying the IIA assumption.

By taking the probability of the first item in the subcategory as the basis, the pair-comparative probability can be expressed as follows:

$$\frac{prob(\psi_{ik,t})}{prob(\psi_{i1,t})} = \frac{exp(\boldsymbol{x}_{i,t}{}^{\mathrm{T}}\beta_{ik})}{exp(\boldsymbol{x}_{i,t}{}^{\mathrm{T}}\beta_{i1})} = exp[\boldsymbol{x}_{i,t}{}^{\mathrm{T}}(\boldsymbol{\beta}_{ik} - \boldsymbol{\beta}_{i1})] \qquad \forall\ i,\ k,\ t, \text{and } k \neq 1; \quad (3\text{-}20)$$

Taking the natural logarithm on both sides of Eq. (3-20) results in the following equation:

$$ln\left[\frac{prob(\psi_{ik,t})}{prob(\psi_{i1,t})}\right] = \boldsymbol{x}_{i,t}{}^{\mathrm{T}}(\boldsymbol{\beta}_{ik} - \boldsymbol{\beta}_{i1}) \qquad \forall\ i,\ k,\ t, \text{and } k \neq 1; \qquad (3\text{-}21)$$

An equation set of subcategories under a specific expenditure category is regarded as an equation system, and it is solved by the seeming unrelated regression (SUR) method. The SUR method assumes that the error terms of each equation of the equation system are related with each other so that the cross-equation error can be considered (Pindyck and Rubinfeld, 1998). Consequently a precise estimation of an individual's expenditure under subcategories with comprehensive economic interpretation can be obtained.

Both the LES model and the MNL model are solved using the statistical software TSP® 5.0. Next, the estimation outcomes can be judged based on the criteria mentioned in Chapter 3.1.1.2 and Chapter 3.1.2.2.

3.5 MSW Discard Model

The regression approach is appropriate to quantify the relationship among the consumption items and the discards of various MSW fractions with a dataset in middle sample size due to abovementioned outcomes in literature review. Multiple-regression analysis can be of use in dealing with modeling among economic variables, policy interventions, and MSW discards for various waste fractions according to the conversion process. Further, in order to account for possible cross-equation correlations, the advanced form of the multiple-regression technique, the SES model, is considered in this study, and the results of SES model and single-equation regressions will be compared.

3.5.1 Model Formulation

Let Θ denotes the set of categories for MSW physical composition, that is, Θ {paper waste, plastic waste,…, etc.}. In the SES model, the discards of MSW by fraction represent the endogenous variables while the exogenous variables comprise the relevant expenditure items and the variables of MSW policy measures, so as to analyze the effects of the consumption expenditure as well as the MSW policy on MSW discards and to define the relationship based on the conversion process discussed earlier. Thus, the relationship can be mathematically represented as follows:

$$\boldsymbol{WE}_{m,t} = \omega(\boldsymbol{x}_{c,t}, \boldsymbol{z}_{k,t}, \ldots) \qquad \forall m,c,k \tag{3-22}$$

where $\{WE_{m,t}\}$ is the set of the amount of MSW fractions, Θ, in year t; $\boldsymbol{x}_{c,t}$ denotes the vector of consumption variables comprising an individual's consumption expenditure on a specific category or subcategory c in year t; $\boldsymbol{z}_{k,t}$ designates the vector of policy variables including dummy or continuous variables; ω is the corresponding waste conversion function.

Furthermore, the SES model also accounts for the changes in lifestyle under the assumption that an individual's consumption behavior is influenced by the changes of lifestyle as shown in keeping with the concept of waste conversion processes during the consumption, as shown in Fig. 2-2.

The SES model can be constructed in some types of model formulation, such as recursive equation system and SUR system, depending on the appearance of the endogenous variables at the left-hand side or right-hand side of the equations, i.e., how the endogenous variables interact with each other (Weng and Chang, 2001). In this study, the SES model is constructed based on the SUR system. In the form of the SUR system, the endogenous variables just appear in the left-hand side of the each equation, and the correlations among the equations are assumed to appear within the error terms of each equation. By such articulation, each equation could use specific explanatory variables. Taking the linear function form for example, the equations for MSW fractions are formulated as follows:

$$\boldsymbol{WE}_{m,t} = \boldsymbol{\alpha}_m + \boldsymbol{x}_{c,t}{}^{\mathrm{T}}\boldsymbol{\delta}_m + \boldsymbol{z}_{k,t}{}^{\mathrm{T}}\boldsymbol{\zeta}_k \qquad \forall m,c,k \tag{3-23}$$

where $\{WE_{m,t}\}$ is the set of the amount of MSW fractions, Θ, in year t; $\boldsymbol{x}_{c,t}$ is the column vector composed of an individual's consumption expenditure on a specific category or subcategory c in year t; $\boldsymbol{z}_{k,t}$ is the column vector of policy variables including dummy or continuous variables; $\boldsymbol{\alpha}_m$, $\boldsymbol{\delta}_c$, and $\boldsymbol{\zeta}_k$ are the column vectors of the parameters. The estimators of parameters (coefficients) denote the marginal effects of the variables on the explained variable in the equations, that is, the change of the explained variable after the change by 1 unit of the explanatory variable. Thus the marginal impacts of the explanatory variables on the explained variable in each equation will be clarified if the estimators of the parameters can be obtained.

3.5.2 Model Estimation and Verification

In order to examine the existence of cross-equation correlation in the equation system, the equation system is firstly established based on single-equation models estimated by the OLS method. Secondly, it would be considered as a SES model and estimated by the SUR method, which involving the generalized least-squares (GLS) estimation gives consistent and efficient estimators for the parameters. If the endogenous variables are correlated intrinsically, the SES model with a reasonable model structure would have a better modeling significance than the outcomes from single-equation models.

By the model set forth here, paper firstly focuses on constructing two types of consumer's behavior model to hierarchically quantify the consumer's behavior, and afterward applies the model to estimate MSW discards in terms of waste fractions.

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Chapter 4 Application of the Estimation Model System of MSW discards

After the accomplishment of the estimation model system of MSW discards, Chapter 4 aims to extend the methodology with an application on MSW management system in terms of the capacity planning and the estimation of GHG emission from the viewpoint of global warming. Thus, Fig. 3-1 can be extended to meet the overall research purpose. The overall model flow diagram can then be demonstrated as Fig. 4-1.

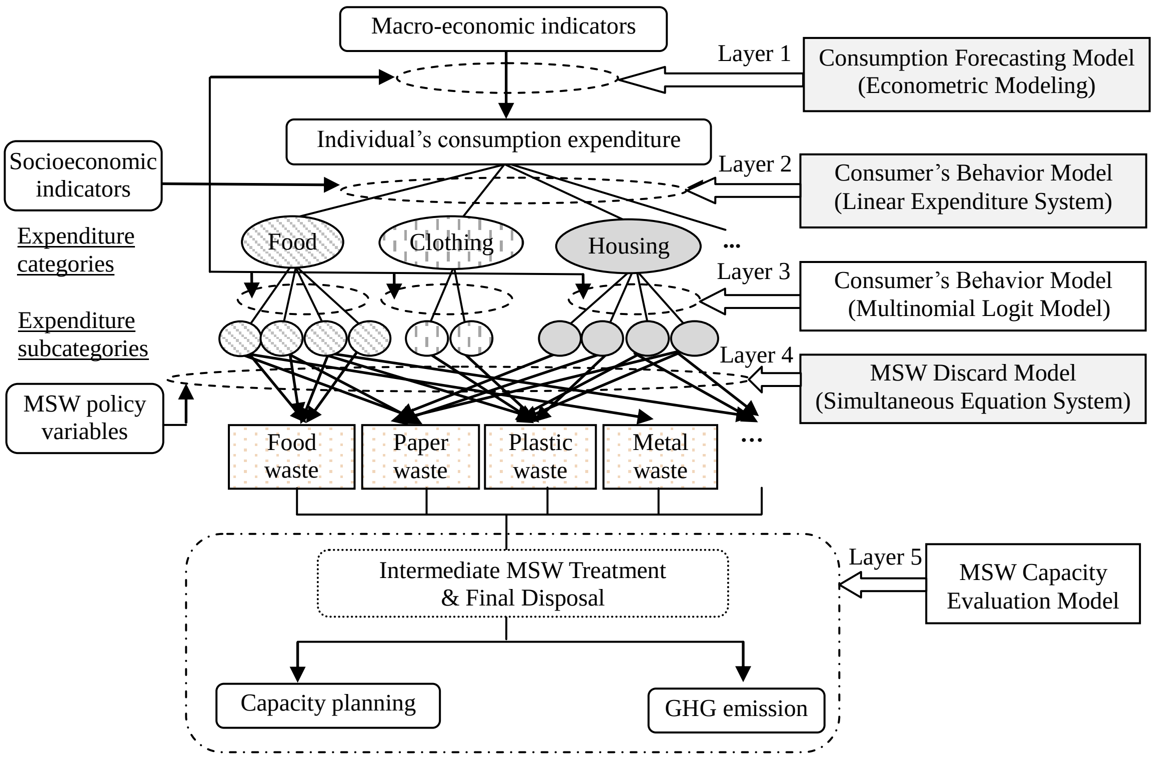

Fig. 4-1 Model flow diagram of the integrated MSW discard modeling with its application on MSW management system.

4.1 Capacity Planning of the MSW Treatment and Disposal System

With the rise of the civilization and urbanization, the MSW management is of importance for the sustainable development. In the practice of the MSW management system, the municipalities have to tickle with the complexities and difficulties in the affairs associated with MSW collection, reuse and recycling, intermediate treatment, and final disposal. In particular, the capacity planning of the MSW treatment and disposal system is a challenging task due to all the uncertainty from the amount and composition of MSW discards as well as from the in-situ operation of the facilities. Meanwhile, the corresponding construction and maintenance cost is burdensome for the local municipalities. Besides, inappropriate intermediate treatment and disposal of MSW would lead to detrimental damage to the public health and natural eco-environmental system (Dyke et al., 1997; Hamer, 2003). Thus the precise projection (or precisely the ex-ante forecasting) of the treatment capacity of MSW treatment and disposal system is particularly crucial from the perspectives of administrative affairs and environmental conservation.

Precise projection of the treatment capacity of MSW treatment and disposal system relies on not only the accurate forecasting of the amount of MSW discards in terms of waste fraction but the possible choices of relevant technologies. The amount and composition of MSW discards in light of the socioeconomic changes should be further considered in the capacity planning of MSW treatment and disposal system. However, the administrative cost is highly uncertain so that it is not considered in this study.

Previous studies have dealt with the mathematical planning of the capacity planning of MSW management system by using the optimization programming methods coupling with fuzzy and grey theories with the constraints in terms of the capacity limitation, financial concerns, as well as the air pollution and leachate impacts (Baetz, 1990; Chang et al., 1997; Huang et al., 1997; Leao, 2001; Li et al., 2008). Their studies mainly highlighted the design capacity and throughput of existing treatment and disposal facilities, the projected amount of MSW generation or discards, if possible, as well as the corresponding cost of respective technology. Based on these earlier studies, a procedure on the projection of required treatment capacity is proposed as follows:

(1) Collect the available data on:
   (a) The amount and composition of MSW discards;
   (b) The distribution of the MSW discards among the MSW treatment and disposal facilities;
   (c) The design capacity and throughput of the MSW treatment and disposal

facilities.

(2) Survey the facility expansion with possible technology options in terms of the MSW treatment and disposal system as well as the detailed data as mentioned in the first item.

(3) Draw the waste flow allocation in the scheduled period based on the projected amount and composition of MSW discards.

However, the options of appropriate MSW treatment technology are particularly emphasized. Besides, the technology option of facility expansion should be considered in terms of the relevant financial cost, environmental impact, social acceptability, and so forth.

4.2 Estimation of the Greenhouse Gas Emission during the MSW Treatment and Disposal

In order to evaluate the GHG emission contributed by MSW treatment and disposal process, IPCC proposed a criteria for estimating GHG emission and revised it in 2006 (IPCC, 2006). The revised estimation procedure made detailed calculation for primary MSW disposal processes, and corrected some irrational assumptions in the estimation (e.g. setting FOD model as default method for estimating methane emission during the landfilling). In this study, major treatment and disposal processes, landfilling, biological treatment, and incineration, are taken into consideration. Actually, some pathways of GHG emission are considered in IPCC's guideline, such as wastewater treatment within the MSW treatment and disposal and open burning. Since the amount of MSW treated by these activities is normally little or without official records, they are out of the scope of this study.

4.2.1 Methane Emission from Disposal of MSW

In the landfilling process, methane (CH_4) is generated due to the decomposition of organic matters under anaerobic condition. Based on IPCC 2006 methodology, the amount of CH_4 generated can be estimated by the following equation (IPCC, 2006):

$$LMEE_{s,t} = \left[\sum_i LMEG_{i,t} - R_t \right] \times (1 - OX_t) \tag{4-1}$$

where $LMEE_{s,t}$ is the overall methane emission in year t (Gg/yr); $LMEG_{i,t}$ is the methane generated by waste fraction i in year t (Gg/yr); R_t is the amount of recovered CH_4 in year t (Gg/yr); OX_t is the oxidation fraction of CH_4 in year t (ratio).

The main mechanism of the decomposition of organic matters in IPCC 2006 methodology is the inducing of first-order decay function to simulate the decomposition process of degradable carbon in the MSW. In order to calculate $LMEG_{i,t}$, firstly it is necessary to estimate the amount of decomposable organic matters (*DOCm*) in disposed MSW, estimating by Eq. (4-2):

$$DDOCm_t = WEL_t \times DOC_t \times DOC_f \times MCF_t \tag{4-2}$$

where $DDOCm_t$ denotes the mass of decomposable *DOCm* deposited in year t (Gg/yr); WEL_t is the mass deposited of MSW discards in year t (Gg/yr) on a dry basis; DOC_t denotes degradable organic carbon in year t, fraction (Gg-C/Gg-waste); DOC_f is the fraction of DOC_t that can be decomposed in year t (fraction); MCF_t is the methane correction factor for aerobic decomposition of deposition in year t (fraction).

The IPCC 2006 methodology emphasizes the "first order decay" principle for the decomposition of $DDOCm_t$, rather than the irrational assumption that the amount of methane emission is proportional to the total amount of MSW dumped within the year (IPCC, 2006; Jha et al., 2008). Assuming the decomposition of $DDOCm_t$ is a first-order reaction, the amount of product will be proportional to the amount of reactant. The methane generation is related to the amount of $DDOCm_t$ deposited. Thus the amount of $DDOCm_t$ accumulated in year t can be calculated by

$$DDOCma_t = DDOCmd_t + \left(DDOCma_{t-1} \times e^{-\kappa} \right) \tag{4-3}$$

where $DDOCma_t$ denotes $DDOCm_t$ accumulated in the landfill sites at the end of year t (Gg/yr), and $DDOCma_{t-1}$ is its lag term (Gg/yr); $DDOCmd_t$ is $DDOCm_t$ deposited into the landfill sites in year t (Gg/yr).

Then $DDOCm_t$ decomposed within the year t can be calculated by

$$DDOCmdecomp_t = DDOCma_{t-1} \times \left(1 - e^{-\kappa} \right) \tag{4-4}$$

where $DDOCmdecomp_t$ is the amount of $DDOCm_t$ decomposed within the year t (Gg/yr); κ is the reaction constant, i.e. κ= ln(2) / $t_{1/2}$ (yr^{-1}), and $t_{1/2}$ is the decaying half-time of $DDOCm_t$, year.

Thus the amount of methane generated can be calculated using

$$LMEG_{s,t} = DDOCmdecomp_t \times F \times 16/12 \quad (4\text{-}5)$$

where $LMEG_{s,t}$ is the amount of methane generated from decomposable matters of one waste fraction within year t (Gg/yr); F is the fraction of methane, by volume, in generated landfill gas (fraction); 16/12 denotes the molecular weight ratio CH_4/C (ratio).

By using Eq. (4-2) to Eq. (4-5), methane emitted within a specific year for one waste fraction can be obtained, and then using Eq. (4-1), the total amount of methane emission from the landfilling of MSW can be obtained and transformed into CO_2 emission equivalence (CO_2 eq.) amount with the coefficient, the global warming potential of methane.

4.2.2 GHG emission from incineration of MSW

IPCC (2006) provided a detailed methodology to estimate the CO_2, methane, and N_2O emission from the incineration process of MSW. Depending on the data attributes, the users can choose appropriate procedures to conduct the estimation. For MSW data on a dry basis, the calculation can be formulated according to the IPCC 2006 methodology Tier 2a.

(1) CO_2 emission

$$ICO_2E_{s,t} = \sum_i \left[\left(WG_{i,t} \times CF_i \times FCF_i \times OF_i \right) \times 44/12 \right] \quad (4\text{-}6)$$

where $ICO_2E_{s,t}$ is the CO_2 emission in year t from the incineration process of MSW for waste fraction s (Gg/yr); $WG_{i,t}$ is the amount of MSW incinerated by composition (on a dry basis), Gg/yr; CF_i is the fraction of carbon in the dry matter (i.e., carbon content) of composition i; FCF_i is the fraction of fossil carbon in the total carbon of composition i; OF_i is the oxidation factor of composition i (fraction); 44/12 denotes the conversion factor from C to CO_2; i is the label for MSW composition category, such as paper, food waste, plastics, etc.

According to Eq. (4-6), the amount of MSW discards by composition on a dry basis is required in the calculation.

(2) Methane emission

$$IMEE_t = WG_{inci,t} \times EFM \times 10^{-6} \tag{4-7}$$

where $IMEE_t$ is the methane emission by incineration in year t (Gg/yr); $WG_{inci,t}$ is the amount of MSW incinerated in year t (Gg/yr), on a wet basis; EFM is aggregate methane emission coefficient (kg-CH_4/Gg-waste); 10^{-6} is the conversion factor from kilogram to gigagram.

(3) N_2O emission

$$IN_2OE_t = WG_{inci,t} \times EFN \times 10^{-6} \tag{4-8}$$

where IN_2OE_t is the N_2O emission by incineration in year t (Gg/yr); $WG_{inci,t}$ is the amount of MSW incinerated in year t (Gg/yr), on a wet basis; EFN is aggregate N_2O emission coefficient (kg-N_2O /Gg-waste); 10^{-6} is the conversion factor from kilogram to gigagram.

Moreover, the global warming potential over a time horizon of 100 years are assumed 1 for CO_2, 2 for CO, 23 for methane, 296 for N_2O (IPCC, 2001).

4.2.3 GHG emission from biological treatment of MSW

In some countries, some part of organic waste, e.g., food waste, garden trimmings, etc., is treated by the biological treatment processes, mainly composting, anaerobic digestion, and mechanical-biological treatment. Primarily, methane and N_2O is released in such a process. The estimation can be formulated as the followings (IPCC, 2006).

(1) Methane emission

$$BMEE_t = \sum_a (M_{a,t} \times EF_a) \times 10^{-3} - R_t \tag{4-9}$$

where $BMEE_t$ is the methane emission in year t from the biological treatment process of MSW (Gg/yr); $M_{a,t}$ is the amount organic waste treated by technology option a (Gg/yr); EF_a is the emission factor for technology option a (g CH_4/ kg waste treated); R_t is amount of methane recovered in year t during the process (Gg/yr).

(2) N_2O emission

$$BN_2OE_t = \sum_a (M_{a,t} \times EF_a) \times 10^{-3} \tag{4-10}$$

where BN_2OE_t is the N_2O emission in year t from the biological treatment processes of MSW (Gg/yr); $M_{a,t}$ is the amount of organic waste treated by technology option a (Gg/yr); EF_a is the emission factor for technology option a (g N_2O / kg waste treated).

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Chapter 5 Case Study

5.1 Background of study area

Taiwan is a small island with limited natural resources, but with one of the densest population around the world (634 persons per km^2, TDGBAS (2008a)), imposing high pressures on the natural environment. Taiwan has achieved significant economic growth in the last few decades by adjusting the economic structure from the agriculture sector to the industry and service sectors. After the 1980s, the industry and service sectors had contributed more than 95% portion of the GDP (see Fig. 5-1). Such transaction on the economic development brought forth apparent changes to all the phases in life. Even, there was liberation in the social and political environment after the abrogation of the Martial Law in 1987. Meanwhile industrialization and urbanization diffused rapidly throughout Taiwan. All these factors influence the individuals' lifestyle and their consumption behavior.

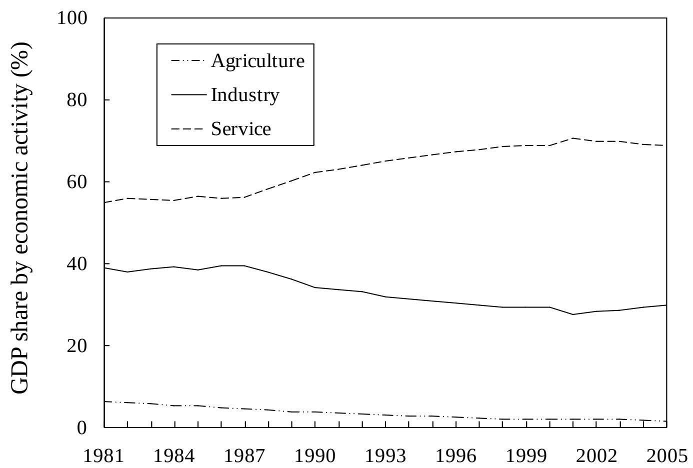

Fig. 5-1 GDP share by economic activity: 1981-2005.

As what developed countries experienced, "mass production, consumption, and mass waste discarded" has been a detrimental trend in the Taiwanese modern life. Fig. 5-2 illustrates the historical records of generation and discards of MSW, as defined in Chapter 2.1 (TEPA, 2008a). Just as other developing countries in Asia, both the series initially increased to a great extent due to the economic development, civilization and urbanization in the last decades; however, the MSW discards slumped in recent years as a result of the implement of MSW policy measures.

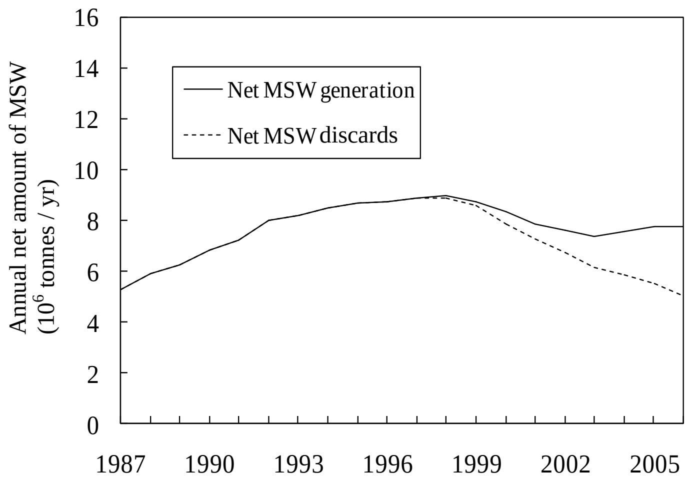

Fig. 5-2 Trends of net MSW generation and discards in Taiwan: 1987-2006.

MSW management has even become a critical issue among the environmental issues due to the increasing waste generation rate and the deficiency of the treatment and disposal facilities. In the 1980's, household waste was even arbitrarily put on the streets for days due to insufficient collecting facilities in some cities. Inappropriate solid waste treatment will result in negative impact on the natural and social economic system. At the end, these detrimental effects will harm the human health.

In order to promote more efficient strategies for the sustainable development in Taiwan, the consumer' behavior, which has been advocated as the driving factor of the environmental problems (see Chapter 2.1), should be analyzed so as to eliminate the environmental loads resulted from the consumption activities, particularly in terms of MSW discard. A more sustainable life style should be found by facilitating the contemporary pattern of consumption, and such information is necessary for the policy design for circular society and circular economy. By eliminating excess consumption, meanwhile, the demand for natural resource and environmental loads could be reduced. Finally a realistic blueprint of sustainable society in Taiwan can be expected.

To achieve the goals abovementioned, Chapter 5 attempts to apply the estimation model system established in Chapter 3 and its application on MSW management discussed in Chapter 4 in Taiwanese case. The modeling works starts at the analysis of the contemporary lifestyle in Taiwan, analyzing the potential driving factors of the consumer's behavior and the MSW discards.

Both comprehensive economic and waste data are collected from the official statistic database to construct the whole picture of the models. Economic data usually has a longer time span than the environmental data; meanwhile, the economic development serves as a key important element in the evolution of the environment. Sustainable development cannot be achieved only if sustainable pattern of consumption and production is formulated. In this study, annual data spanning 25 years (1981-2005) are used in the model development. The socioeconomic indices and the household expenditure obtained from official databases (TDGBAS, 2008b) in Taiwan are analyzed when modeling the consumption's behavior. Meanwhile, the MSW composition data on a dry basis during the period from 1992 to 2004 and the overall per capita MSW generation and discards data during the period from 1987 to 2006 are used in the model development.

5.2 Socioeconomic Analysis associated with the Lifestyle Changes in Taiwan

As mentioned previously, both the political and socioeconomic environment had changed rapidly over the past decades in Taiwan; such changes led to the changes of the individuals' lifestyles and then affected the generation of environmental loads. Owing to the absence of an absolute definition of the word "lifestyle", as earlier discussed in Chapter 2, this concept is still difficult to be defined and quantified. Thus the socioeconomic indices are used in representing the lifestyle based on the assumption that the entire society in Taiwan is viewed as an aggregate group. Table 5-1 lists the major socioeconomic and household-attribute indices, institutively associated with the changes in lifestyle on the basis of the discussion in Chapter 2.1 and Chapter 3.2. In this study, these indices are regarded as the indicators representing the contemporary lifestyle, and Table 5-2 reports their changes over this period. As shown in Table 5-2, all the indices had changed significantly over this period.

Table 5-1 Description of the representative indices related to the changes in lifestyle in Taiwan.

Indices	Description	Unit
$Popu_t$	The total population	million capita
$Hhld_t$	The number of households	10^4 household
$Hlbrr_t$	The ratio of the employee in the household member	%
$Hpop_t$	The household size	capita
$Aveage_t$	The average age of the population	age
$Hun15r_t$	The percentage of the population that is aged 15 years and younger.	%
$Hov65r_t$	The percentage of the population that is aged 65 years and older.	%
SF_t	The rate of families in which the number of persons per household is less than 5	%
WK_t	The female proportion in the labor force	%
$Gini_t$	The gini coefficient (an indicator for the income lag between the poor and the rich)	%
$Engel_t$	The Engel rate	%
$Unemployment_t$	The unemployment rate in the labor force	%
$Saving_t$	The saving rate in the disposable expenditure	%
$Cons_t$	Annual per capita overall consumption expenditure	10^4 NT$ at 2001 prices

Table 5-2 Changes in indices related to the changes in lifestyle in Taiwan: 1981–2005.

Socioeconomic variables and household attribute indices	Increase rate (%)
$Popu_t$	27.62
$Hhld_t$	88.27
$Hlbrr_t$	20.14
$Hpop_t$	-32.22
$Aveage_t$	31.70
$Hun15r_t$	- 42.00
$Hov65r_t$	116.37
SF_t	31.82
WK_t	26.43
$Gini_t$	21.00
$Engel_t$	-40.11
$Unemployment_t$	203.68
$Saving_t$	-15.08
$Cons_t$	257.52

Examining the economical indices change within this period, several characteristics are revealed. Large population is the most important driving force of environmental loads. From Table 5-2, the population in Taiwan rose approximately by 28% from 1981 to 2005, resulting in almost the highest population density all over the world (634 persons per km^2, TDGBAS (2008a)). One significant socioeconomic change is the population structure by age, i.e., the population aging problem— more elder, less child generation. The population of the elder (more than age 65) rose by 116.37%; meanwhile, the average age of total population grew up to 31.7% over the period because of the improved health care system and medical technology. Whereas, the population of the younger (less than age 15) decreased by 42%. Such population changes cause the average labor age to get higher; meanwhile, the young graduates are forced to spend longer time to look for jobs. Thus the unemployed rate of labor force even increased by 203.68 %. Also, the aging problem may be a potential risk for the environmental problems.

As for other socioeconomic indicators, reviewing Table 5-2, a decreasing *Engel* coefficient by 40.11% over the period implies that the individual reduced the budget on food; alternatively, people have more potential to consume the goods except for the subsistent ones. On the contrary, the gradually increasing *Gini* coefficient by 21% infers that an uneven distribution of wealth has widened between urban and rural areas, and pushes more woman of low income level to work for salaries (career woman population increased by 26.43%). Interestingly the saving rate of the individual’s disposable income decreased approximately by 15%, implying the change of citizens’ consumption behavior and more household consumption.

Moreover, Fig. 5-3 illustrates the trends of these indices with normalized time series data; almost all the curves appear absolutely monotonous trends (excluding the saving rate and the unemployment rate), implying the existence of a strong intrinsic driving force resulted from the changes in lifestyle. Even, the high correlation coefficients (see Table 5-3) among the indices confirm their intrinsic interaction. Such evolution may be viewed as a characteristic of a developing country.

After reviewing the changes in the socioeconomic indices associated with the lifestyle changes, it is of interest to identify the influencing factors of the individual’s consumption pattern. Afterward, per capita consumption expenditure by detailed categories is to be analyzed.

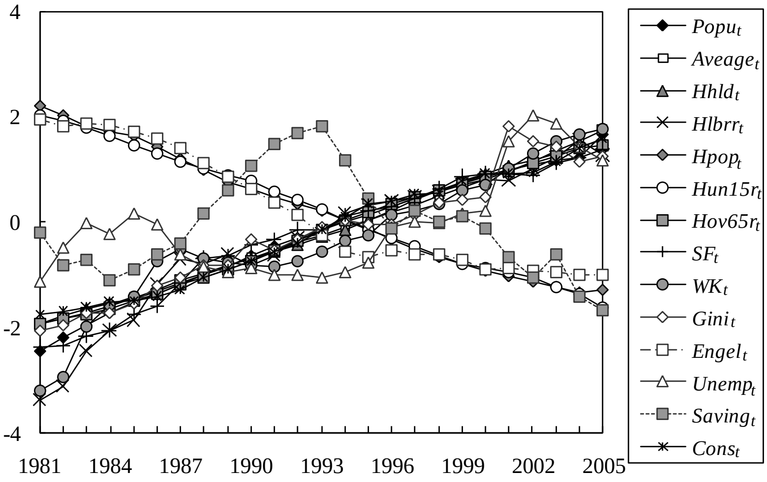

Fig. 5-3 Normalized time series data of the variables associated with the changes in lifestyle: 1981-2005.

Table 5-3 Correlation matrix of the representative indices related to the lifestyle changes: 1981-2005.

	$Hhld_t$	$Hpop_t$	$Hlbr_t$	$Aveage_t$	$Hun15r_t$	$Hov65r_t$	SF_t	WK_t	$Gini_t$	$Engel_t$	$Unemployment_t$	$Saving_t$	$Cons_t$
$Hhld_t$	1.000	-0.994*	0.951*	0.998*	-0.998*	0.997*	0.976*	0.952*	0.971*	-0.959*	0.696*	-0.157	0.993*
$Hpop_t$	-0.994*	1.000	-0.969*	-0.991*	0.995*	-0.996*	-0.990*	-0.949*	-0.971*	0.976*	-0.637*	0.070	-0.990*
$Hlbr_t$	0.951*	-0.969*	1.000	0.953*	-0.961*	0.958*	0.978*	0.971*	0.936*	-0.942*	0.558*	-0.008	0.943*
$Aveage_t$	0.998*	-0.991*	0.953*	1.000	-0.997*	0.996*	0.975*	0.956*	0.970*	-0.954*	0.692*	-0.159	0.992*
$Hun15r_t$	-0.998*	0.995*	-0.961*	-0.997*	1.000	-0.999*	-0.982*	-0.953*	-0.965*	0.967*	-0.663*	0.130	-0.996*
$Hov65r_t$	0.997*	-0.996*	0.958*	0.996*	-0.999*	1.000	0.982*	0.943*	0.967*	-0.975*	0.658*	-0.110	0.997*
SF_t	0.976*	-0.990*	0.978*	0.975*	-0.982*	0.982*	1.000	0.940*	0.957*	-0.975*	0.547*	0.027	0.974*
WK_t	0.952*	-0.949*	0.971*	0.956*	-0.953*	0.943*	0.940*	1.000	0.940*	-0.879*	0.711*	-0.209	0.926*
$Gini_t$	0.971*	-0.971*	0.936*	0.970*	-0.965*	0.967*	0.957*	0.940*	1.000	-0.935*	0.701*	-0.099	0.953*
$Engel_t$	-0.959*	0.976*	-0.942*	-0.954*	0.967*	-0.975*	-0.975*	-0.879*	-0.935*	1.000	-0.507*	-0.076	-0.975*
$Unemployment_t$	0.696*	-0.637*	0.558*	0.692*	-0.663*	0.658*	0.547*	0.711*	0.701*	-0.507*	1.000	-0.702	0.643*
$Saving_t$	-0.157	0.070	-0.008	-0.159	0.130	-0.110	0.027	-0.209	-0.099	-0.076	-0.702*	1.000	-0.120
$Cons_t$	0.993*	-0.990*	0.943*	0.992*	-0.996*	0.997*	0.974*	0.926*	0.953*	-0.975*	0.643*	-0.120	1.000

Note: * denotes correlation is significant at the 1% level (two-tailed).

Table 5-4 lists the category classified on the consumption expenditure in Taiwan. The category classification was slightly adjusted during the period from 1992 to 1994 due to some new policy measures (primarily the mandatory public health insurance). Fig. 5-4 presents the time series data of the annual per capita consumption expenditure by categories from 1981 to 2005, and Table 5-5 further shows the changes in an individual's expenditure by category over the period. Undoubtedly all the categories of expenditure changed significantly with the changes in lifestyle. Per capita consumption expenditure increased by around 204 % over the period. Moreover, per capita consumption expenditure on "medicines and medical care", "transportation &

Table 5-4 Categories of per capita consumption expenditure in Taiwan.

Category	Subcategory	
Food (Fd_t)	Cereals and cereal products Meat and meat products	($Fd_{1,t}$)
	Milk and milk products	($Fd_{2,t}$)
	Fruits	($Fd_{3,t}$)
	Miscellaneous food commodity	($Fd_{4,t}$)
	Food from restaurant	($Fd_{5,t}$)
	Beverages	($Fd_{6,t}$)
	Tobacco and betel nut	($Fd_{7,t}$)
Clothing ($Cloth_t$)	Garments	($Cloth_{1,t}$)
	Footwear	($Cloth_{2,t}$)
Housing ($House_t$)	Residential rent	($House_{1,t}$)
	Maintenance and repairs	($House_{2,t}$)
	Water supply	($House_{3,t}$)
	Facility insurance fee	($House_{4,t}$)
	Electricity and gas supply	($House_{5,t}$)
Household appliances (HA_t)	Furniture	($HA_{1,t}$)
	Fabric products	($HA_{2,t}$)
	Household durable equipment	($HA_{3,t}$)
	Tableware and other utensils	($HA_{4,t}$)
	Housekeeping services	($HA_{5,t}$)
Medicines & medical care (Med_t)	Medical supplies and appliances (including the fee of the clinics)	($Med_{1,t}$)
	Medical equipment and supplement	($Med_{2,t}$)
	Medicines and health food	($Med_{3,t}$)
	Health insurance	($Med_{4,t}$)
Transportation & communication ($Trans_t$)	Transportation and communication equipment	($Trans_{1,t}$)
	Maintenance and repair charge of transportation equipment	($Trans_{2,t}$)
	Transportation fees and insurance	($Trans_{3,t}$)
	Communication services	($Trans_{4,t}$)
Amusement & education (AE_t)	Traveling expenses	($AE_{1,t}$)
	Entertainment expenses	($AE_{2,t}$)
	Book, newspapers and periodicals	($AE_{3,t}$)
	Entertainment equipment	($AE_{4,t}$)
	Educational expenses	($AE_{5,t}$)
Miscellaneous items (Mis_t)	Miscellaneous commodities	($Mis_{1,t}$)
	Financial services	($Mis_{2,t}$)
	Cosmetic items	($Mis_{3,t}$)
	Hair cutting and shower	($Mis_{4,t}$)
	Personal care services	($Mis_{5,t}$)
	Wedding and funeral expenses (excluding of food charges)	($Mis_{6,t}$)
	Miscellaneous expenses	($Mis_{7,t}$)
	Other non-saving insurance expenses	($Mis_{8,t}$)

Note: a. Few classifications of subcategories were adjusted during the period of 1992 to 1994;
b. Name in the parentheses denotes the variable name in the model development.

communication", "amusement & education", "miscellaneous items" increased even by over 300 % over the period. These items appear to represent the modern lifestyle in the civilized society.

Apparently, all of the consumption expenditures by category are changed and dominated by the individual's consumption preferences. Thus, how the lifestyle changes affect the consumer' behavior is of importance in analyzing the consumer's behavior so as to evaluate the sustainability of the contemporary pattern of consumption.

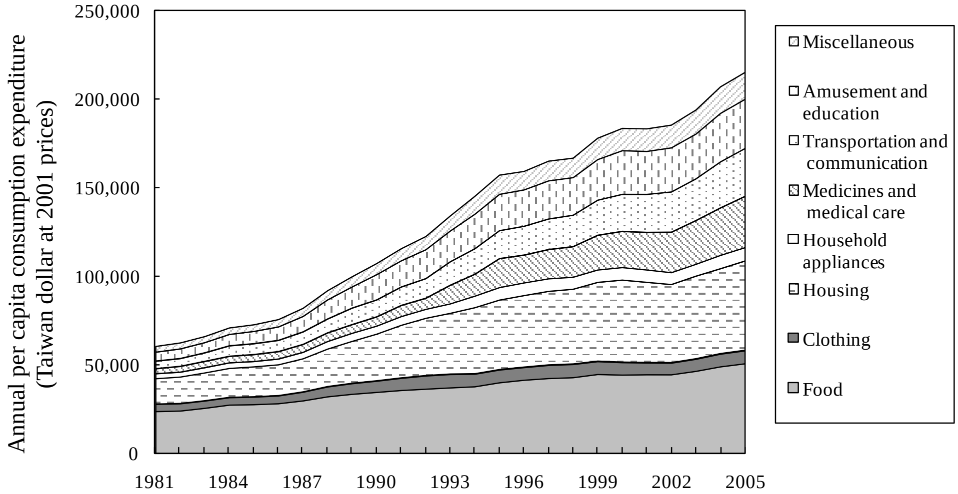

Fig. 5-4 Structure of individual's consumption expenditure in Taiwan: 1981 to 2005.

Table 5-5 The changes in an individual's consumption expenditure by category in Taiwan: 1981–2005.

Category of expenditure	Increase rate (%)
Annual per capita expenditure	249.37
Food	114.11
Clothing	78.76
Housing	245.67
Household appliances	181.80
Medicines & medical care	965.41
Transportation & communication	551.74
Amusement & education	459.54
Miscellaneous items	372.25

5.3 Review of the MSW Management Legislations and Policy Measures in Taiwan

5.3.1 The Situation of MSW Generation and Treatment

Considering the changing lifestyle in Taiwan, the Taiwan Environmental Protection Administration (TEPA) and its previous administrations have executed several countermeasures to control the rapidly growing solid waste discards from the households and the industries since 1974 (TEPA, 2008a). At the beginning, the TEPA cooperated with the municipalities to promote the establishment of the MSW collection, treatment, and disposal system. Subsequently, the MSW collection rate, representing the portion of the MSW discard collected by the local municipalities, has been promoted up to more than 95% since 1990. Meanwhile, the MSW disposal rate, representing the portion of MSW under the recycling, treatment and disposal by the municipalities, was improved significantly from 60.93% in 1990 to 90.17% in 2000, even up to more than 95% since 2002. Furthermore, the TEPA has bulletined the fundamental laws and supportive regulations in terms of environmental management and MSW affairs; subsequently, several administrative projects using economic instruments, e.g., taxation, deposit, green-label, charge and fees, etc., have been imposed to control the MSW generation and discard (Bor et al., 2004; Lu et al., 2006; TEPA, 2008b).

Fig. 5-5 illustrates the official records of the composition structure of MSW discards in Taiwan; data in terms of waste composition is reported from 1992 to 2004 on a dry basis while per capita overall MSW discards is available from 1988 to 2006 (TEPA, 2008c). MSW is classified into eight categories by physical property for the treatment and final disposal planning. Since the MSW composition analysis was conducted on a dry basis before 2004, the moisture of waste is separated and taken as a single category (however, the analysis changes into wet-basis since 2005). By such classification, essential information can be obtained for designing the recycling, treatment, and disposal plans.

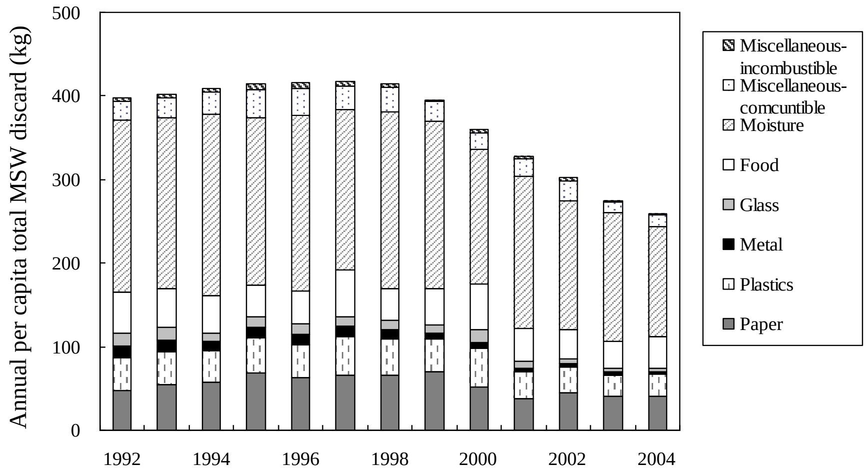

Fig. 5-5 Structure of per capita MSW discards in Taiwan: 1992 to 2004 (based on a dry-basis survey).

In Fig. 5-4, per capita overall MSW discards has a decreasing trend in recent years due to MSW policy interventions. Initially, the people in Taiwan did not take note of the importance of waste problems. Almost all waste was dumped directly into landfill sites without proper separation. By the 1980s, some landfill sites were completely filled, and some cities did not even have spaces to temporarily dump MSW. At that time, the TEPA adopted incineration as the treatment approach instead of the landfilling. The first incinerator was operated in 1992, and most incinerators planned by the TEPA were operated during the period from 1998 to 2001, following which, they handled more than 45% of MSW. Fig. 5-6 presents the share of the MSW discards treated by intermediate treatment and disposal facilities (including the landfills, incinerators, dumping, and other disposal sites) (TEPA, 2008c). Fig. 5-7 depicts the trends of the recycling rate, which denotes the portion of the recycled materials within the MSW generation and the incineration rate of MSW discards. In fact, these two indicators are used as a policy target in terms of MSW management in Taiwan. Since the land resources is limited in Taiwan, the national environmental plan aims at treating 80% of the amount of MSW discards by incineration in 2006 (TEPA, 1998), and actually the portion of MSW treated by incineration exceeded the target value (82.79%) of the plan. Even after 2007, a new regulation ordered that combustible waste not be dumped in the landfills until it is incinerated so as to improve the recycling activities and reduce the MSW volume (TEPA, 2008a). However, another potential risk would rise in the future since some incinerators are operated with insufficient MSW feed, which is resulted from the unequally allocated incinerators. The actual throughput of the incinerators is still smaller than the design capacity (see Table 5-6, (TEPA, 2008d; TEPA, 2008e)). Hence, the regional MSW transportation and treatment network have to be constructed as soon as possible.

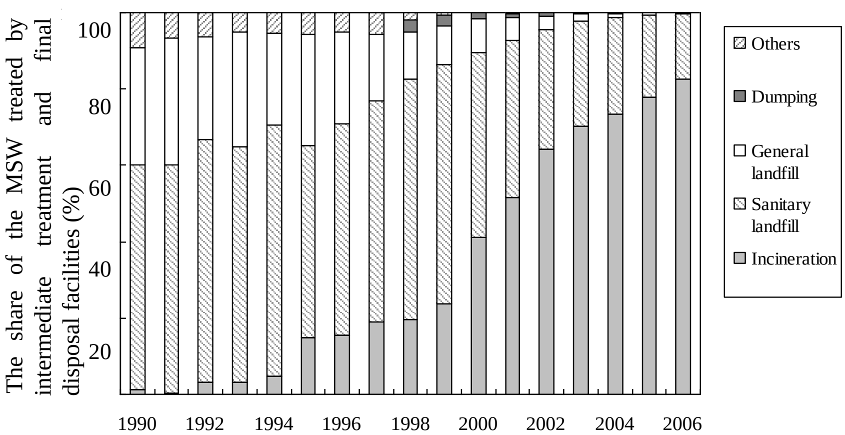

Fig. 5-6 The share of the MSW discards treated by intermediate treatment and final disposal facilities: 1990-2006.

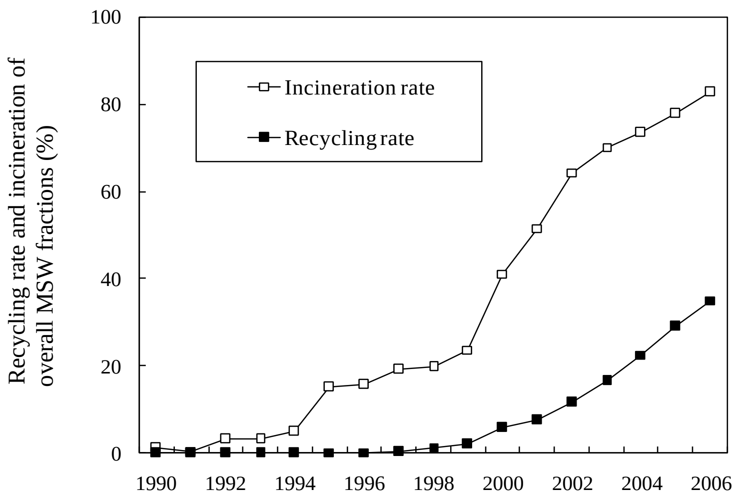

Fig. 5-7 Historical trends of the recycling rate and the incineration rate of overall MSW fractions in Taiwan: 1990-2006.

Table 5-6 Basic information of the major MSW intermediate treatment and final disposal facilities in Taiwan.

Type	Number	Design capacity (tonnes/year)	Throughput (tonnes/year)[a]
Landfill site	163	--	864,354
Incinerator	22	7,672,500 [b]	4,163,968

Note: [a] The amount refers to the data in 2006.

[b] The operation period is assumed as 330 days per year.

5.3.2 MSW Legislations and Policy Measures

According to supportive regulations, several administrative projects using economic instruments have played important roles in controlling MSW discard (Bor et al., 2004; Lu et al., 2006; TEPA, 2008a). The MSW policy measures based on the "polluter pays principle" can be categorized by three types: the "command and control" type, the "economic instruments" (e.g., the subsidy, the tax, the charge, the deposit, etc.) type, and the mixed type. Primarily, the MSW management system in Taiwan is designed according to the "3R" principle (reduce, reuse, and recycle). The national environmental plan (TEPA, 1998) has set up several target values for MSW management (see Table 5-8). In order to achieve the ultimate goal of developing a "zero waste society", promoting the recycling rate of potential resources and reducing excess utilization of the commodities of plastics are the short-term objective.

Table 5-7. The short-term policy targets for MSW management (TEPA, 1998).

Index	Target year			
	1996	2001	2006	2011
MSW Recycling rate (%)	7	25	45	50
MSW disposal rate (%)	80	85	90*	90
Incineration rate (%)	19.52	70	80*	80

Note: * denotes that the target value has been achieved in the scheduled year.

Since the land resource is limited in Taiwan, it is inevitable to choose the incineration as the main intermediate treatment technology. Meanwhile, the "not in my backyard" effect arose. Many protests against the construction of the landfills and the incinerators occurred due to the possible health risk from the MSW intermediate treatment and final disposal facilities, especially for the incinerator. In order to reduce the dioxin pollution of the incinerators, TEPA imparted extensive social education to the citizens in order to reduce the moisture of wastes and conduct MSW separation. MSW policy measures can be classified into national-level and city-level types.

City-level policy measures

The first important MSW elimination project, "Keep Trash off the Ground", was implemented in Taipei city in 1995 while this project nowadays has been extended to the majority of urban areas in Taiwan. This policy stipulates that citizens can not directly dump their waste at the collection sites; instead, the residents have to hand their waste to the workers at the collection cars. This measure successfully eliminates the leachate draining away from MSW during collecting process. In addition, if citizens mishandle over the waste to the collection cars, they have to keep the waste in their house. To a certain extent, households have to reduce the amount of their waste discard. However, this project requires an enormous administrative budget to sustain its performance; therefore, it is implemented only within the major urban areas.

Local municipalities also started to decrease MSW collection frequency and to impose MSW treatment charge in different ways depending on different cities. For example, the Taipei city started to charge MSW treatment fee for standardized collection bag from 2000 while some of the local municipalities charge MSW treatment fee based on the fee of household water usage. Even, 14 counties have started to recycle the used plastic bags within the MSW collection system from 2006. Besides, non-governmental groups play an important role in local recycling programs.

National-level policy measures

The first national-wide project, “Resource Recycling Four-in-One Project”, has been launched since 1998. This project not only improved the waste recycling networks but also aroused public concern over issues related to MSW. In order to control the dioxin emitted by incinerators, in 2002 TEPA started limiting the use of plastic bags and some plastic products (“Restrictions on the Use of Plastic Bags”).

In 2004, the “Review and Prospect of Solid Waste Treatment” project set the ultimate goal of the MSW management system—promoting a “zero waste society”, which emphasizes the importance of the “Reducing”. However, a great amount of efforts by the municipalities have to be imparted on the environmental education to facilitate the current consumption pattern and to encourage the reuse along with the recycling activities, that is, to change the lifestyle of the citizens. In order to achieve this goal, in 2004 TEPA imposed stricter classification standards (the “Mandatory Recycling of MSW” project) for MSW collection in Taipei city and extended the regulation to all of Taiwan in 2005; food waste and potential resources in MSW had to be collected separately from the general MSW. Moreover, the waste food oil is bulletined as one recyclable material from the end of 2007.

Table 5-8 summarizes the important regulations and administrative projects pertaining to the MSW management in Taiwan. To date, frontier regulations and projects are still being proposed and executed.

Mainly the MSW policy measures are designed to improve the “3R” works, especially the “recycling”, by bulleting several kinds of mandatory recyclable materials. The municipalities are responsible for the recycling activities. Such efforts can be revealed through the increasing trend of the recycling rate (see Fig. 5-7). The “command and control” type of policy measures seem to work well while the annual per capita MSW discard continues decreasing in recent years (see Fig. 5-4).

Table 5-8 Major regulations and policy measures on MSW management in Taiwan.

Regulation			
Law	Supplemental regulation	Effective date	Brief description
Waste Clean-up Act		26/07/1974	The first law for solid waste management. Give a fundamental definition of solid waste and its categories. Clarify the obligation and responsibility of the waste management affairs.
	Charge of Clean-up and Treatment Charge for MSW	31/07/1991	Regulate the charge for MSW treatment to citizens on the basis of "Polluter Pays Principle".
	Recycle, Clean-up, and Treatment of MSW	23/04/1997	Regulate the classification, collection, treatment technology, and treatment facility on waste recycling issues.
	Recycling General Waste Items by Implementation Agency	17/04/2006	Regulate potential resource items that should be collected by the local government.
	Management Criteria for Public Landfill facilities	01/01/2007	Regulate combustible MSW not be dumped in the landfill sites until it is being incinerated.
Environmental Fundamental Law		11/12/2002	Provide a fundamental law for sustainable development. Promote green consumption, recycling, reuse, life cycle analysis of product, and clean production in waste management system.
Resource Reuse and Recycling Act		03/07/2002	Provide the definitions of recycling items and fundamental principles. Clarify the obligation and responsibilities of the recycling of goods.
	Restrictions of Product Over-Packaging	01/07/2006	Restrict the size and weight of specific commodities including: cookies, cosmetics, wine, drinks, refined foods, packaged goods, present box, etc.

Source: TEPA, 2008a; TEPA, 2008b.

Table 5-8 Major regulations and policy measures on MSW management in Taiwan. (*cont.*)

Administrative project		
Project	Duration	Brief description
Keep Trash off the Ground	1995 till date (firstly official adopted by local government)	Stop the use of cargo for fixed point waste collection; instead, the households have to directly dump their waste in the trash car. Ban on temporal dumping at the MSW collection sites.
Resource Recycling Four-in-One Project	01/1997 till date	Build an integrated recycling network among citizens (community), private recycle companies (the recycling industry), local government, and recycling foundation. Improve the business value of reuse, recycling, and treatment.
Restrictions on the Use of Plastic Bags	01/07/2002 till date	Impose restrictions on the utilization of packages and tableware, which are composed of styrofoam and plastics.
Review and Prospect of Solid Waste Treatment	12/2004 till date	Examine the previous solid waste generation trends and treatment capacity. Propose the 'zero-disposal society' as the final goal of the solid waste policy.
Mandatory Recycling of MSW	01/2005 till date	Regulate that households have to make a strict classification of waste before the collection by the local government. The bulletined items that can be sorted include the following: (a) Combustible general waste (b) Food waste (c) Waste of potential resources (d) Furniture and waste of large size.
Recycling of General Plastic Bags	05/2006 till date	Recycle the plastic bags with the MSW collection system in major 14 counties.
Recycling of Waste Food Oil	09/2007 till date	Include "waste food oil" as one item on the bulletined mandatory recycle substance list for specific food and service companies. Encourage households to collect waste oil, which is used in making food, and use it as a raw material in the bio-fuel production industry.

Source: TEPA, 2008a; TEPA, 2008b.

5.4 Model Development and Implication

After reviewing the evolution of the socioeconomic situation and MSW management in Taiwan, in this section, the methodology designed in Chapter 3 and Chapter 4 would be applied to the Taiwanese case. The modeling work would start at the consumption forecasting function, followed by the consumer' behavior model as well as the MSW discard model. By the built models, influencing factors on the consumer's preferences as well as its impacts on the MSW discards in terms of waste fraction can be found, and thus, concrete strategies can be proposed to facilitate the consumer's behavior and support the policy design towards a low waste society.

5.4.1 Development of the Estimation Model System of MSW Discards

Applying the methodology established in Chapter 3, the estimation model system is designed to model the waste conversion processes. As shown in Fig. 3-1, the estimation model system, comprising (1) the consumption forecasting model, (2) the consumer's behavior model, and (3) the MSW discard model, would be consecutively carried out in the Taiwanese case study.

5.4.1.1The Consumption Forecasting Model

In order to estimate future MSW discard the consumption forecasting model is introduced to the projection system in this study and serves as the first-layer model for the estimation model system (see Fig. 3-1). Considering econometric modeling approaches, the single-equation regression model is considered in the development of the forecasting model, and the SES modeling would be supplemented if the single-equation modeling does not work well. The consumption theories mentioned in Chapter 3.3 would be induced in fitting the consumption pattern in Taiwan over the estimation period.

Firstly, the linear formulations are developed for the respective hypotheses of the consumption theories with the statistical software TSP® 5.0. Since the models are developed on a national level, the macro socioeconomic indicators would serve as the explanatory variables in the models. Since the individual's life-time income is difficult to estimate, the life-cycle income hypothesis is not included in the model development. Model-1 is based on Eq. (3-6); Model-2 is designed n the basis of Eq. (3-10), and Model-3 refers to Eq. (3-13); in addition, Model-4, as an extension of Model-3, induces socioeconomic variables into the Permanent Income Hypothesis.

Taking a look at Fig. 5-4, the structure change of the overall per capita consumption expenditure seems to appear in the series around 1984. After the preliminary trials, the data spanning from 1984 to 2003 provides the most convincing outcomes, and the ex-post period is assigned as the period from 2004 to 2006, testing the stability of the model. The regression results using the ordinary least-squares method are reported in Table 5-9, and the modeling fitting curves are compared with the true value of the explained series, shown in Fig. 5-8.

Table 5-9 Results of the single-equation models for the consumption forecasting model.

Explanatory variable	Model-1	Model-2	Model-3	Model-4
	Absolute income hypothesis	Relative income hypothesis	Permanent income hypothesis	Permanent income hypothesis
	Explained variable: $PCons_t$			
Constant	-0.461 (-1.53)			
$PCons_{t-1}$			0.542 (4.15^{**})	0.550 (4.74^{**})
$PGDP_t$	0.425 (44.36^{**})	0.294 (2.75^{**})	0.199 (3.89^{**})	0.209 (4.57^{**})
$PGDP_{t-1}$		0.123 (1.10)		
$Unemp_t$				-0.187 (-2.35^{*})
LM heter.	0.07	0.001	1.96	1.60
DW statistic	0.67	0.51	---	---
Durbin-h statistic	---	---	2.06^{*}	1.22
$MAPE_{1984\text{-}2003}$ (%)	2.59	2.71	1.83	1.56
$MAPE_{2004\text{-}2005}$ (%)	1.51	1.13	1.71	2.09
Adjusted R^2	0.990	0.990	0.993	0.996

Note: a. $PCons_t$ denotes the annual per capita gross domestic product (GDP) in year t, Taiwan dollar (10^4 NT$) at 2001 prices; $PCons_{t-1}$ is the on-year lag of $PCons_t$; $PGDP_t$ denotes the annual per capita gross domestic product (GDP) in year t, Taiwan dollar (10^4 NT$) at 2001 prices; other variables use the same definitions as Table 5-1.

b. LM heter. designates the LM statistic for heteroscedasticity.

c. Durbin-h statistic is used in Model 3 and Model 4, instead of DW statistic, because the lag term of $PCons_t$ is used as one of the explanatory variables.

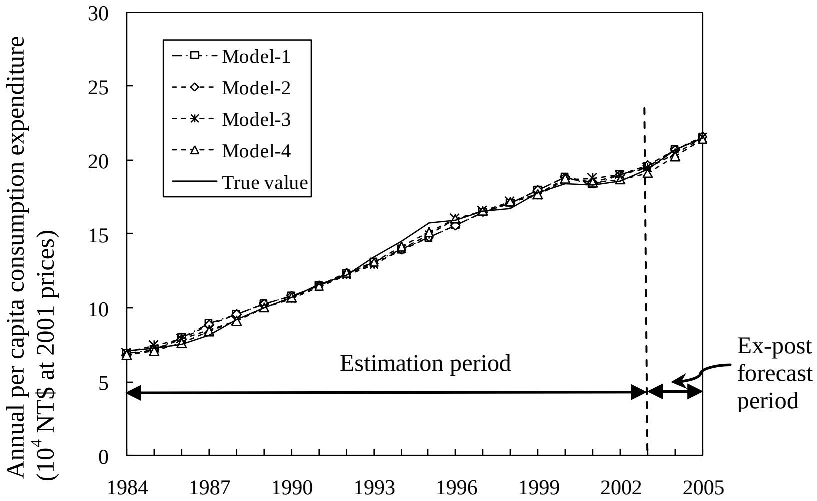

Fig. 5-8 Model fitting curves and the true value of the annual per capita consumption expenditure.

The small values of the MAPE for both the estimation period and ex-post forecasting period imply that all the models are fit well. The significant values of "goodness-of-fit", represented by the adjusted R^2, also confirm the fitting performances. Moreover, the fitting curves in Fig 5-8 appear to catch the major trends of the true series, consistent with the high adjusted R^2 values.

As for the statistical diagnose of the respective equation, the multicollinearity is excluded since almost the *t* statistics of the estimators are significant. The DW and Durbin-h statistics suggest that serial correlation problem does not occur in Model 4 while slight violation exists in the three equations. In addition, the insignificant LM statistics for heteroscedasticity in all the equations imply that the error terms can be considered homogenous.

Accordingly, statistically consistent and efficient estimators of the parameters are obtained in the four equations. Since most of the statistical requirements are satisfied in the established single-equation models, there is no crucial need to develop a multi-equation model for this case study.

Checking the norms of the estimators of the parameters, the negative estimator of the constant term in Model-1 violates the assumption of the Absolute Income Hypothesis, and even it is insignificant. In Model-2, the multicollinearity exists in the two explanatory variables and thus the estimators are not significant. On the other hand, the outcomes from Model-3 and Model-4 are reasonable and statistically convincing. Therefore, the estimation results suggest that the Permanent Income Hypothesis can well describe the consumption pattern in Taiwan over the period.

As for the model implication, the highly collinear socioeconomic variables (as shown in Table 5-3) make it difficult to induce all the desired explanatory variables in the model development. Indeed, the unemployed rate ($Unemp_t$) is influencing in the models, and the signs of the parameters are reasonable, implying that the three variables are influencing factors for the consumption patterns in Taiwan over the period.

However, seeing Fig. 5-8, the true series shows that the irreversibility of consumption does not always hold in the Taiwanese case study since the annual per capita consumption expenditure decreased around 2001. The economic slump in 2001 turned the consumption down in that year. However, the estimates from Model-3, which applies the original form of the theory, do not reflect the change; on the contrary, Model-4 does. Consequently, Model-4 in terms of the widely adopted expectation Permanent Income Hypothesis is considered as the model in decision for the consumption forecasting model since its statistical performance is superior to others to a certain extent and precisely catches the characteristics of the series. Model-4 can be represented as follows:

$$\boldsymbol{PCons}_t = 0.209 \times \boldsymbol{PGDP}_t + 0.550 \times \boldsymbol{PCons}_{t-1} - 0.187 \times \boldsymbol{Unemp}_t$$

In the regression model, the parameter of the explanatory variable implies the marginal effect of the variable on the explained variable; thus, quantitative effects of the explanatory variables on per capita consumption expenditure can be clearly identified in the equations. The marginal effect designates the change of the explained variable after the change by 1 unit on the explanatory variable. From the Model-4, the increases of $PGDP_t$ by 10^4 NT$ (at 2001 prices) is associated with the increase of $PCons_t$ by approximately 2,090 NT$ (at 2001 prices); the increases of $Unemp_t$ by 1% involves the decrease of $PGDP_t$ by around 1,870 NT$ (at 2001 prices); besides, the consumption has an inertia by 55%. Therefore, the coefficients of the explanatory variables have important implications for clarifying the influencing factors of the annual per capita consumption.

5.4.1.2 The Consumer's Behavior Model

In the previous section, per capita consumption expenditure is well explained by the macroeconomic indicators. This section would apply the LES model and MNL model, as mentioned in Chapter 3.4, to simulate the distribution of per capita consumption expenditure, and tries to identify the controlling factors in the consumer's behavior.

As discussed in Chapter 5.2, twelve important indices reflecting lifestyle changes in Taiwan are chosen as the candidates of explanatory variables in the model development. As shown in Fig. 5-2 and Table 5-3, the high multicollinearity existing among eleven variables again suggests the existence of the underlying mechanism of economic development and the changes in lifestyle. Therefore, only the most representative and uncorrelated indices should be selected as explanatory variables in order to confirm the best estimators. Thus, after preliminary trials, $Hov65r_t$ and $Saving_t$ are chosen as the exogenous variables in the LES and MNL models with regards to the "aging" phenomenon as well as the socioeconomic condition in Taiwan.

5.4.1.2.1 The LES Model

The LES model is applied in the analysis of the annual per capita consumption expenditure by category. Equations of categories comprise a model system, and subsequently the equations are solved simultaneously. In other words, the SES technique is used. Based on the principles mentioned in Chapter 3.1 (also see Fig. 3-2), firstly, rational explanatory variables are used in each equation, and secondly, the equation system is tested by the identification condition.

In the LES model of Taiwanese case, eight equations corresponding to the commodity categories are established with the two explanatory variables, $Hov65r_t$ and $Saving_t$. The results of the identification diagnosis of the LES model set forth here are shown in Table 5-10. Since all the equations of the equation system satisfy the identification condition (exactly identified), the equation system of the LES model can be estimated.

Table 5-10 Diagnosis of Identification for the LES model.

Equation of the LES model	G	K	G^*	K^*	$G^*+K^*=G-1$	Identification status
Food	8	2	7	0	○	exactly identified
Clothing	8	2	7	0	○	exactly identified
Housing	8	2	7	0	○	exactly identified
Household Appliances	8	2	7	0	○	exactly identified
Medicines & Medical Care	8	2	7	0	○	exactly identified
Transportation & Communication	8	2	7	0	○	exactly identified
Amusement & Education	8	2	7	0	○	exactly identified
Miscellaneous	8	2	7	0	○	exactly identified

Afterward, the LES model is specified by 3SLS method with the statistical software TSP® 5.0. After the preliminary trials, the data spanning from 1984 to 2003 produce the most meaningful outcomes, and the ex-post period is assigned as the period from 2004 to 2005, testing the stability of the model; Table 5-11 reports the results. The small values of the MAPE both for the estimation period and ex-post forecasting period imply that all the models are fit well, and the significant values of "goodness-of-fit", represented by the adjusted R^2, also confirm the modeling performances. Furthermore, Fig 5-9 illustrates the modeling results of the LES model; it appears that all the curves are fitted well and catch the major trends of the true series.

Table 5-11 Results of the LES model.

Exogenous variable	Endogenous variable							
	Fd_t	$Cloth_t$	$Hous_t$	HA_t	Med_t	$Trans_t$	AE_t	Mis_t
Constant	3,078.42	- 5,424.56	- 28,476.90	- 2,969.70	- 4,686.87	- 8,822.35	- 21,008.90	- 7,326.67
	(0.97)	(-4.13**)	(-2.14*)	(-0.71)	(-0.72)	(-4.57**)	(-4.12**)	(-1.96)
$Hov65r_t$	4,285.88	583.41	6,495.71	861.97	4,700.24	4,109.17	4,366.70	2,230.54
	(18.54**)	(6.10**)	(7.18**)	(2.82**)	(9.87**)	(29.25**)	(11.77**)	(8.19**)
$Saving_t$	146.06	288.52	424.93	81.62	- 654.19	- 256.71	252.69	- 4.81
	(1.41)	(6.72**)	(0.98)	(0.60)	(-3.06**)	(-4.07**)	(1.52**)	(-0.04)
α_i	0.088	0.029	0.348	0.105	0.169	0.043	0.123	0.096
	(2.07*)	(2.09*)	(8.47**)	(5.29**)	(3.73**)	(1.40)	(4.79**)	(6.98**)
DW statistic	0.83	1.27	1.55	1.09	1.78	1.17	2.12	1.40
$MAPE_{1984\text{-}2003}$ (%)	1.44	2.42	1.62	4.66	5.85	3.17	1.76	2.10
$MAPE_{2004\text{-}2005}$ (%)	3.24	5.79	5.00	6.85	0.63	4.01	1.26	1.59
Adjusted R^2	0.974	0.916	0.993	0.916	0.979	0.986	0.991	0.991

Note: a. values in the parentheses denote the t value;
b. * and ** denote significance at the 5% and 1% levels, respectively.

As for the statistical diagnose of the respective equation, multicollinearity is excluded since the *t* statistics of the estimators are significant; the DW statistics also suggest that serial correlation problem does not appear in most equations. In addition, Fig. 5-10 plots the residuals of the model fitting estimates. Since no significant trend exists in the residual figures, the error terms can be considered homogenous. Based on the abovementioned outcomes, the estimators of the parameters are statistically consistent and efficient.

In Table 5-11, most of the estimators in the LES model are significant and with reasonable norms of the coefficients; thus, the results are convincing. $Hov65r_t$ has a significantly positive coefficient, indicating that the aging population in Taiwan is in favor of increasing the subsistence value of the consumption expenditure. The positive coefficient of $Saving_t$ in some categories of expenditure suggests that in the subsistence level of consumption, people are willing to save money to buy the commodities belonging to these categories; on the other hand, the categories with a negative coefficient of $Saving_t$ indicate that the consumption of the commodities belonging to these categories is competitive to the saving budget for the commodities with higher utility or for investment.

The annual per capita subsistence level of consumption and the marginal budget share are estimated by the LES model, and the results are summarized in Table 5-12. The average per capita annual subsistence level of consumption over the period is 141,286.54 Taiwan dollar (NT$ at 2001 prices; however), this value is a little lower than the average minimum legal labor wage during the period (NT$160,661.65 at 2001 prices) (TCLA, 2008). Even, Fig. 5-11 depicts the time series of the estimated series for per capita consumption expenditure, the subsistence level of consumption, and the average minimum labor wage. In Fig. 5-11, after 2003, the consumption expenditure and the subsistence level of consumption started to exceed the minimum legal labor wage. Such outcome implies that the actual purchasing power for the low-income individual is quite limited. Besides, a large subsistence value of one expenditure category suggests that the commodities in this category would be the necessities.

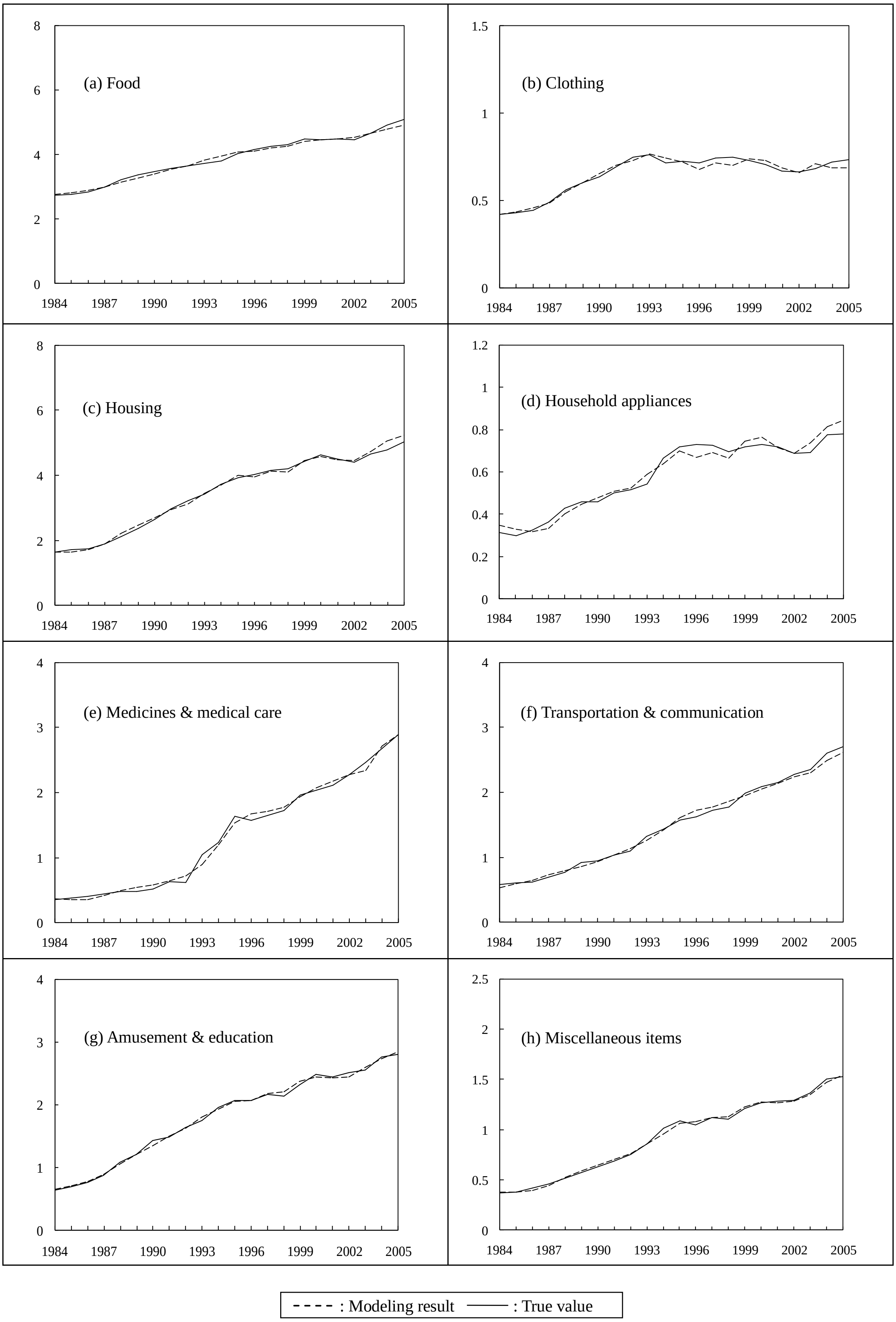

Fig. 5-9 Model fitting curves of the LES model.

Note: The estimation period and ex-post forecast period denote the period of 1984-2003 and 2004-2005, respectively.

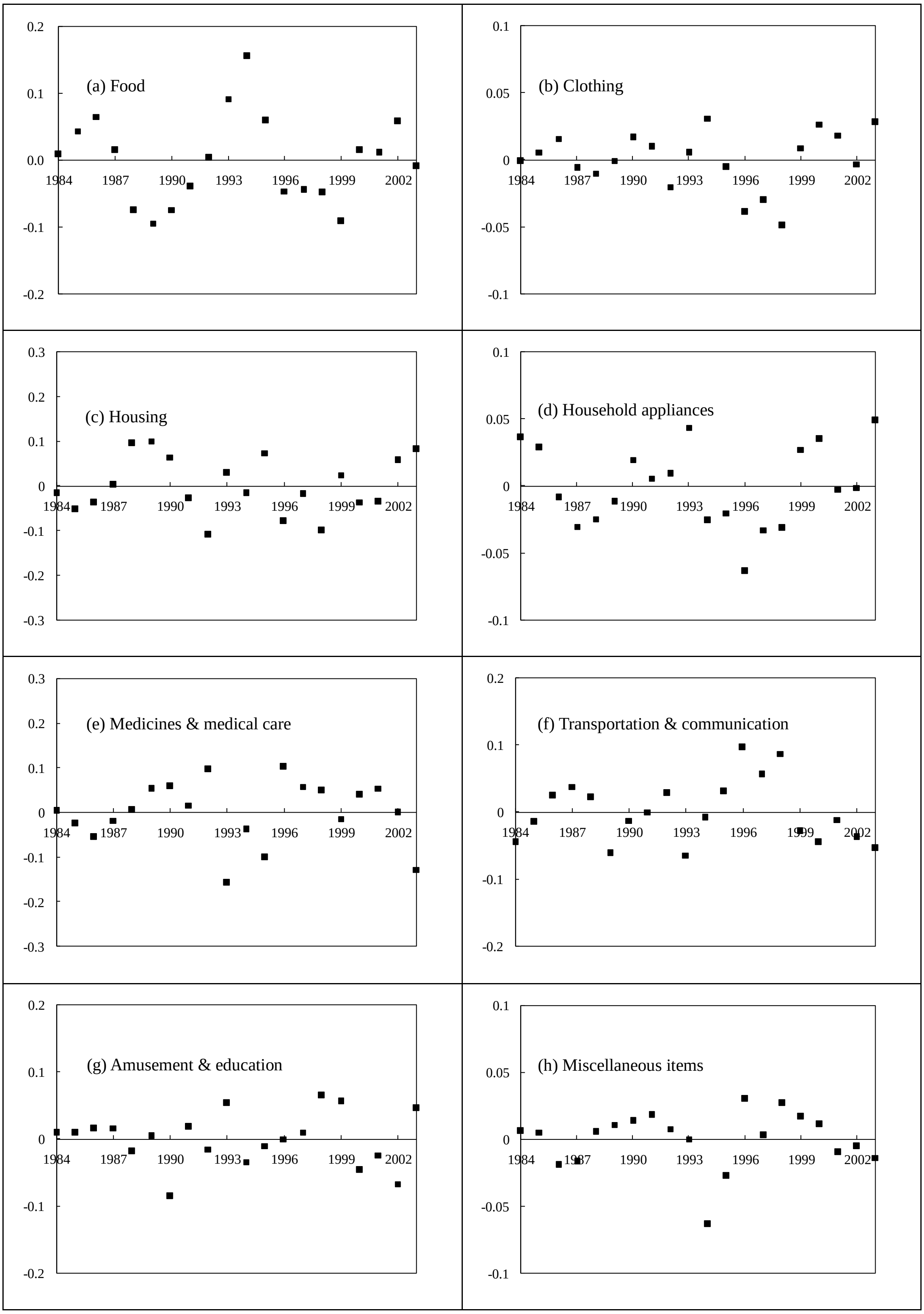

Fig. 5-10 Residual plots of the LES model.

Table 5-12 Estimates of the average subsistence value of the annual per capita consumption expenditure by categories and the marginal budget share by the LES model.

Categories of expenditure	Average annual per capita subsistence value (NT$ at 2001 price basis)		Marginal budget share (%)
Food	37,452.88	(28.4%)	8.8
Clothing	6,347.02	(4.8%)	2.9
Housing	32,200.09	(24.5%)	34.8
Household Appliances	5,323.10	(4.0%)	10.5
Medicines & Medical Care	11,510.88	(8.7%)	16.9
Transportation & Communication	13,660.44	(10.4%)	4.3
Amusement & Education	16,756.30	(12.7%)	12.3
Miscellaneous	8,429.40	(6.4%)	9.6
Summation	131,680.21	(100%)	100.0

Note: The value in the parenthesis denotes the share of each category in average annual per capita subsistence value.

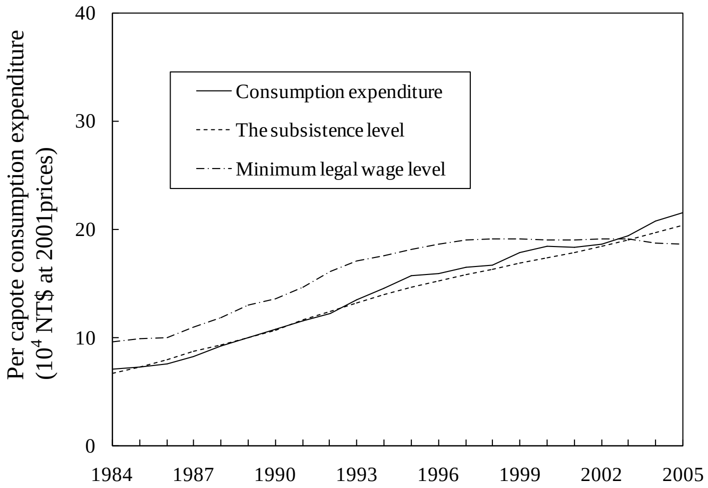

Fig. 5-11 Time series plot of estimated per capita consumption expenditure, the subsistence level of consumption, and the minimum legal wage level: 1984-2005.

From Table 5-12, the individual's consumption expenditure on "food" and "housing" occupy the most portions in the individual's subsistence level of consumption, implying the commodities and services of the two categories are essential to the individual's life. Furthermore, a large value of marginal budget share of one expenditure category indicates that the consumption on such expenditure category would reflect the individual's "expressive behavior", which is argued by Schor (2005), that is, the individual purchases the commodities of the expenditure category to obtain the utilities for extravagant enjoyment. Besides, from Table 5-12, it can be concluded that the individual's consumption expenditure on "housing", "medicines & medical care", and "amusement & education" influences the consumer's preferences most in the non-subsistence level of consumption.

Comparing the estimates of the marginal budget share in the categories of consumption expenditure in Table 5-12, the ratios of the categories in the subsistence level of consumption is different from the values of the marginal budget share, implying that although individuals pay most on "food" and "housing", the marginal budget share for "food" is lower than the portion of "food" in the subsistence level of consumption. Such result is in agreement with the intuitional concept: people are willing to spend much for other commodities with extravagant enjoyment after satisfying the subsistence level of consumption. Thus the results of the LES model can quantitatively define the relationship among people's expenditures by category with the further economic interpretation.

5.4.1.2.2 The MNL Model

In the development of the LES model for the distribution of categories of the annual per capita consumption expenditure, $Hov65r_t$ and $Saving_t$ are found to be influential variables affecting the consumer's behavior. Subsequently, by using the same explanatory variables, the MNL models, discussed in Chapter 3.4.2, are established for each category of consumption expenditure modeling the consumer's behavior among the subcategories within one category.

As mentioned in Chapter 3.4.2, the SUR approach is applied in the development of the MNL models. Since the SUR approach is one of the SES techniques, the model identification test is required. The equations are designed for modeling the annual per capita consumption expenditure for the subcategories of one category, comprising an equation system. In the same way, respective equation system corresponding to the categories of the consumption expenditure can be developed.

Afterward, Table 5-13 represents the identification diagnosis of the respective equation system of the MNL models. Among the consumption categories, the MNL model for the clothing category is built with the single-equation modeling since there are only two subcategories within the clothing category. From Table 5-13, all the equations of the equation system satisfy the identification condition (exactly identified) so that the estimation of the equation systems is achievable.

The estimation and ex-post forecasting periods are set the same as the LES mode, during the period from 1984 to 2003, and from 2004 to 2005, respectively. Table 5-14 presents the results of the MNL models, solved with the statistical software TSP® 5.0, for the distribution of an individual's consumption expenditure on each subcategory. The results of the MNL model show the relationship between the logarithm of the probability of the choice-pairs and the influential factors, revealing the individual's consumption propensity.

Most of the equations exhibit significant parameters, again, suggesting that $Hov65r_t$ and $Saving_t$ server as key factors to affect the consumer's preferences in the detailed distribution of per capita consumption expenditure. Besides, the high adjusted R^2 are obtained for most equations though some equation for the subcategories got low fitting performance, which may be due to the dramatic changes of the data, unobserved influencing explanatory variables, or the creditability of the data.

Since the parameter denotes the relative propensity between the two choice sets, a positive parameter indicates that one factor signifies the propensity for the individual to select the *k-th* minor category instead of the reference one. Hence, the results of the MNL model simulate the consumption decision process by quantifying the relative propensity so as to explore the fine structure of the consumer's preferences. However, the estimation accuracy indicators, MAPEs, for some equations are large. The large biases may be due to the large span of the original data on detailed categories, and thus lower the performance of the models.

Furthermore, Fig 5-12 illustrates the modeling results of the MNL models; it appears that most of the curves are fitted well and consistent with the major trends of the true series.

Table 5-13 Diagnosis of Identification for the MNL models.

Equations of the respective equation system of the MNL models	G	K	G^*	K^*	$G^*+K^*=G-1$	Identification status
Food						
$ln(Fd_{2,t}/Fd_{1,t})$	6	2	5	0	○	exactly identified
$ln(Fd_{3,t}/Fd_{1,t})$	6	2	5	0	○	exactly identified
$ln(Fd_{4,t}/Fd_{1,t})$	6	2	5	0	○	exactly identified
$ln(Fd_{5,t}/Fd_{1,t})$	6	2	5	0	○	exactly identified
$ln(Fd_{6,t}/Fd_{1,t})$	6	2	5	0	○	exactly identified
$ln(Fd_{7,t}/Fd_{1,t})$	6	2	5	0	○	exactly identified
Housing						
$ln(House_{2,t}/House_{1,t})$	4	2	3	0	○	exactly identified
$ln(House_{3,t}/House_{1,t})$	4	2	3	0	○	exactly identified
$ln(House_{4,t}/House_{1,t})$	4	2	3	0	○	exactly identified
$ln(House_{5,t}/House_{1,t})$	4	2	3	0	○	exactly identified
Household Appliances						
$ln(HA_{2,t}/HA_{1,t})$	4	2	3	0	○	exactly identified
$ln(HA_{3,t}/HA_{1,t})$	4	2	3	0	○	exactly identified
$ln(HA_{4,t}/HA_{1,t})$	4	2	3	0	○	exactly identified
$ln(HA_{5,t}/HA_{1,t})$	4	2	3	0	○	exactly identified
Medicines & Medical Care					○	exactly identified
$ln(Med_{2,t}/Med_{1,t})$	3	2	2	0	○	exactly identified
$ln(Med_{3,t}/Med_{1,t})$	3	2	2	0	○	exactly identified
$ln(Med_{4,t}/Med_{1,t})$	3	2	2	0	○	exactly identified
Transportation & Communication						
$ln(Trans_{2,t}/Trans_{1,t})$	3	2	2	0	○	exactly identified
$ln(Trans_{3,t}/Trans_{1,t})$	3	2	2	0	○	exactly identified
$ln(Trans_{4,t}/Trans_{1,t})$	3	2	2	0	○	exactly identified
Amusement & Education						
$ln(AE_{2,t}/AE_{1,t})$	4	2	3	0	○	exactly identified
$ln(AE_{3,t}/AE_{1,t})$	4	2	3	0	○	exactly identified
$ln(AE_{4,t}/AE_{1,t})$	4	2	3	0	○	exactly identified
$ln(AE_{5,t}/AE_{1,t})$	4	2	3	0	○	exactly identified
Miscellaneous						
$ln(Mis_{2,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified
$ln(Mis_{3,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified
$ln(Mis_{4,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified
$ln(Mis_{5,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified
$ln(Mis_{6,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified
$ln(Mis_{7,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified
$ln(Mis_{8,t}/Mis_{1,t})$	7	2	6	0	○	exactly identified

Note: The MNL model for clothing is developed as a single-equation model, rather than the SES approach.

Table 5-14 Results of the MNL model for each subcategories of the annual per capita consumption expenditure.

Exogenous variable / Endogenous variable		$Constant_{tik}$ - $Constant_{ti1}$	$Hov65r_{tik}$ - $Hov65r_{ti1}$	$Saving_{tik}$ – $Saving_{ti1}$
$ln(Fd_{2,t} / Fd_{1,t})$	parameter	-3.631	0.195	-0.011
$\bar{R}^2$=0.960, LM for heter. = 0.01, DW = 1.32, $MAPE_{1984\text{-}2003}$ = 5.22%, $MAPE_{2004\text{-}2005}$ = 27.88%	*t* value	-26.23**	20.37**	-1.89
$ln\ (Fd_{3,t} / Fd_{1,t})$	parameter	-2.775	0.151	0.008
$\bar{R}^2$=0.942, LM for heter. = 2.14, DW = 0.84, $MAPE_{1984\text{-}2003}$ = 7.24%, $MAPE_{2004\text{-}2005}$ = 27.51%	*t* value	-20.42**	15.75**	1.54
$ln\ (Fd_{4,t} / Fd_{1,t})$	parameter	-4.319	0.171	0.016
$\bar{R}^2$=0.906, LM for heter. = 2.31, DW = 1.13, $MAPE_{1984\text{-}2003}$ = 6.19%, $MAPE_{2004\text{-}2005}$ = 18.26%	*t* value	-19.72**	11.45**	1.75
$ln\ (Fd_{5,t} / Fd_{1,t})$	parameter	-13.363	0.055	0.206
$\bar{R}^2$=0.940, LM for heter. = 9.18**, DW = 1.14, $MAPE_{1984\text{-}2003}$ = 14.83%, $MAPE_{2004\text{-}2005}$ = 38.04%	*t* value	-16.07**	4.22**	5.00**
$ln\ (Fd_{6,t} / Fd_{1,t})$	parameter	-3.711	0.147	0.003
$\bar{R}^2$=0.866, LM for heter. = 0.44, DW = 0.90, $MAPE_{1984\text{-}2003}$ = 7.56%, $MAPE_{2004\text{-}2005}$ =10. 62%	*t* value	-17.11**	9.87**	0.29
$ln\ (Fd_{7,t} / Fd_{1,t})$	parameter	-2.192	-0.050	-0.003
$\bar{R}^2$=0.842, LM for heter. =2.63, DW = 2.08, $MAPE_{1984\text{-}2003}$ = 4.98%, $MAPE_{2004\text{-}2005}$ = 26.15%	*t* value	-25.82**	-8.70**	-0.76
$ln\ (Cloth_{2,t} / Cloth_{1,t})$	parameter	-1.398	0.179	-0.047
$\bar{R}^2$=0.975, LM for heter. = 0.08, DW = 1.69, $MAPE_{1984\text{-}2003}$ = 3.83%, $MAPE_{2004\text{-}2005}$ =21.47%	*t* value	-14.51**	27.30**	-11.57**
$ln\ (House_{2,t} / House_{1,t})$	parameter	-2.810	0.027	-0.003
$\bar{R}^2$=0.110, LM for heter. = 4.98, DW = 1.17, $MAPE_{1984\text{-}2003}$ = 16.26%, $MAPE_{2004\text{-}2005}$ = 49.33%	*t* value	-7.72**	1.10	-0.17
$ln\ (House_{3,t} / House_{1,t})$	parameter	-2.188	-0.043	-0.041
$\bar{R}^2$=0.955, LM for heter. = 0.60, DW = 1.82, $MAPE_{1984\text{-}2003}$ = 2.44%, $MAPE_{2004\text{-}2005}$ =6.81%	*t* value	-28.55**	-8.23**	-12.75**
$ln\ (House_{4,t} / House_{1,t})$	parameter	-3.561	-0.264	-0.037
$\bar{R}^2$=0.785, LM for heter. = 2.39, DW = 1.55, $MAPE_{1984\text{-}2003}$ = 17.49 %, $MAPE_{2004\text{-}2005}$ = 17.09%	*t* value	-6.11**	-6.66**	-1.52
$ln\ (House_{5,t} / House_{1,t})$	parameter	0.382	-0.189	-0.031
$\bar{R}^2$=0.991, LM for heter. = 2.59, DW = 0.81, $MAPE_{1984\text{-}2003}$ = 3.66%, $MAPE_{2004\text{-}2005}$ = 17.02%	*t* value	5.06**	-36.81**	-9.89**
$ln\ (HA_{2,t} / HA_{1,t})$	parameter	0.420	-0.062	-0.022
$\bar{R}^2$=0.668, LM for heter. = 1.08, DW = 0.77, $MAPE_{1984\text{-}2003}$ = 8.62%, $MAPE_{2004\text{-}2005}$ = 20.73%	t value	1.86	-4.07**	-2.32*
$ln\ (HA_{3,t} / HA_{1,t})$	parameter	0.384	-0.049	-0.003
$\bar{R}^2$=0.301, LM for heter. = 1.76, DW = 0.49, $MAPE_{1984\text{-}2003}$ = 32.23%, $MAPE_{2004\text{-}2005}$ = 77.76%	*t* value	1.23	-2.31*	-0.21
$ln\ (HA_{4,t} / HA_{1,t})$	parameter	0.007	-0.107	-0.013
$\bar{R}^2$=0.721, LM for heter. = 3.11, DW = 0.53, $MAPE_{1984\text{-}2003}$ = 11.17%, $MAPE_{2004\text{-}2005}$ = 22.31%	*t* value	0.03	-5.65**	-1.15
$ln\ (HA_{5,t} / HA_{1,t})$	parameter	0.829	0.077	-0.019
$\bar{R}^2$=0.409, LM for heter. =2.21, DW = 0.77, $MAPE_{1984\text{-}2003}$ = 11.98%, $MAPE_{2004\text{-}2005}$ = 7.25%	*t* value	2.54*	3.48**	-1.42

Note: a. * and ** denote significance at the 5% and 1% levels, respectively.

b. LM heter. denotes the LM statistic for heteroscedasticity.

Table 5-14 Results of the MNL model for each subcategories of the annual per capita consumption expenditure (*cont.*).

Endogenous variable \ Exogenous variable		$Constant_{tik}$ - $Constant_{ti1}$	$Hov65r_{tik}$ - $Hov65r_{ti1}$	$Saving_{tik}$ – $Saving_{ti1}$
$ln\ (Med_{2,t} / Med_{1,t})$	parameter	4.973	-0.410	0.008
$\bar{R}^2$=0.912, LM heter. = 1.51, DW = 1.10, $MAPE_{1984\text{-}2003}$ = 19.12%, $MAPE_{2004\text{-}2005}$= 55.59%	*t* value	10.51^{**}	-12.75^{**}	0.41
$ln\ (Med_{3,t} / Med_{1,t})$	parameter	4.064	-0.221	-0.045
$\bar{R}^2$=0.730, LM heter. = 9.24^{**}, DW = 0.50, $MAPE_{1984\text{-}2003}$ = 17.39%, $MAPE_{2004\text{-}2005}$ = 26.74%	*t* value	6.73^{**}	-5.39^{**}	-1.80
$ln\ (Med_{4,t} / Med_{1,t})$	parameter	2.179	0.102	0.004
$\bar{R}^2$=0.477, LM heter. = 0.83, DW = 1.23, $MAPE_{1984\text{-}2003}$ = 17.71%, $MAPE_{2004\text{-}2005}$ = 16.65%	*t* value	4.18^{**}	2.88^{**}	0.18
$ln(Trans_{2,t} / Trans_{1,t})$	parameter	2.519	0.041	-0.079
$\bar{R}^2$=0.553, LM heter. = 0.60, DW = 0.79, $MAPE_{1984\text{-}2003}$ = 14.09%, $MAPE_{2004\text{-}2005}$ = 4.53%	*t* value	5.36^{**}	1.27	-4.01^{**}
$ln\ (Trans_{3,t} / Trans_{1,t})$	parameter	2.329	-0.009	-0.086
$\bar{R}^2$=0.532, LM heter. = 0.76, DW = 0.68, $MAPE_{1984\text{-}2003}$ = 13.50%, $MAPE_{2004\text{-}2005}$= 40.69%	*t* value	4.70^{**}	-0.28	-4.14^{**}
$ln\ (Trans_{4,t} / Trans_{1,t})$	parameter	2.690	0.061	-0.135
$\bar{R}^2$=0.507, LM heter. = 1.91, DW = 0.56, $MAPE_{1984\text{-}2003}$ = 25.61%, $MAPE_{2004\text{-}2005}$= 21.10%	*t* value	3.72^{**}	1.24	-4.47^{**}
$ln\ (AE_{2,t} / AE_{1,t})$	parameter	-0.074	0.058	-0.052
$\bar{R}^2$=0.729, LM heter. = 1.71, DW = 1.16, $MAPE_{1984\text{-}2003}$ = 6.20%, $MAPE_{2004\text{-}2005}$ = 14.00%	*t* value	-0.41	4.74**	-6.80**
$ln\ (AE_{3,t} / AE_{1,t})$	parameter	1.062	-0.175	-0.039
$\bar{R}^2$=0.912, LM heter. = 1.65, DW = 0.84, $MAPE_{1984\text{-}2003}$ = 8.26%, $MAPE_{2004\text{-}2005}$ = 7.24%	*t* value	4.31^{**}	-10.45^{**}	-3.78^{**}
$ln\ (AE_{4,t} / AE_{1,t})$	parameter	1.451	-0.115	-0.057
$\bar{R}^2$=0.798, LM heter. = 7.85^{*}, DW = 0.68, $MAPE_{1984\text{-}2003}$ = 9.08%, $MAPE_{2004\text{-}2005}$ = 4.50%	*t* value	4.32^{**}	-5.06^{**}	-4.07^{**}
$ln\ (AE_{5,t} / AE_{1,t})$	parameter	2.373	-0.004	-0.069
$\bar{R}^2$=0.796, LM heter. = 0.18, DW = 1.49, $MAPE_{1984\text{-}2003}$ = 8.69%, $MAPE_{2004\text{-}2005}$ = 4.01%	*t* value	10.84^{**}	-0.24	-7.57^{**}
$ln\ (Mis_{2,t} / Mis_{1,t})$	parameter	-3.123	0.192	-0.030
$\bar{R}^2$=0.361, LM heter. = 1.46, DW = 1.17, $MAPE_{1984\text{-}2003}$ = 30.41%, $MAPE_{2004\text{-}2005}$ = 15.09%	*t* value	-3.38^{**}	3.06^{**}	-0.77
$ln\ (Mis_{3,t} / Mis_{1,t})$	parameter	1.788	0.086	-0.065
$\bar{R}^2$=0.484, LM heter. = 0.03, DW = 0.93, $MAPE_{1984\text{-}2003}$ = 15.02%, $MAPE_{2004\text{-}2005}$ = 7.85%	*t* value	4.36^{**}	3.08^{**}	-3.78^{**}
$ln\ (Mis_{4,t} / Mis_{1,t})$	parameter	2.354	-0.045	-0.053
$\bar{R}^2$=0.520, LM heter. = 2.33, DW = 0.85, $MAPE_{1984\text{-}2003}$ = 14.63%, $MAPE_{2004\text{-}2005}$ = 13.26%	*t* value	5.62^{**}	-1.58	-3.03^{**}
$ln\ (Mis_{5,t} / Mis_{1,t})$	parameter	0.911	0.056	-0.045
$\bar{R}^2$=0.322, LM heter. = 0.04, DW = 1.00, $MAPE_{1984\text{-}2003}$= 13.92%, $MAPE_{2004\text{-}2005}$ = 12.87%	*t* value	2.24^{*}	2.02	-2.67^{**}
$ln\ (Mis_{6,t} / Mis_{1,t})$	parameter	1.644	-0.070	-0.050
$\bar{R}^2$=0.507, LM heter. = 2.60, DW = 0.96, $MAPE_{1984\text{-}2003}$ = 17.42%, $MAPE_{2004\text{-}2005}$ = 30.17%	*t* value	3.36^{**}	-2.10^{*}	-2.46^{*}
$ln\ (Mis_{7,t} / Mis_{1,t})$	parameter	1.844	-0.232	-0.081
$\bar{R}^2$=0.838, LM heter. = 0.18, DW = 1.49, $MAPE_{1984\text{-}2003}$ = 19.94%, $MAPE_{2004\text{-}2005}$ = 47.40%	*t* value	3.55^{**}	-6.57^{**}	-3.73^{**}
$ln\ (Mis_{8,t} / Mis_{1,t})$	parameter	5.311	0.279	-0.283
$\bar{R}^2$=0.830, LM heter. = 2.46, DW = 1.06, $MAPE_{1984\text{-}2003}$ = 21.77%, $MAPE_{2004\text{-}2005}$ = 64.85%	*t* value	7.37^{**}	5.69^{**}	-9.41^{**}

Note: a. * and ** denote significance at the 5% and 1% levels, respectively.

b. LM heter. denotes the LM statistic for heteroscedasticity.

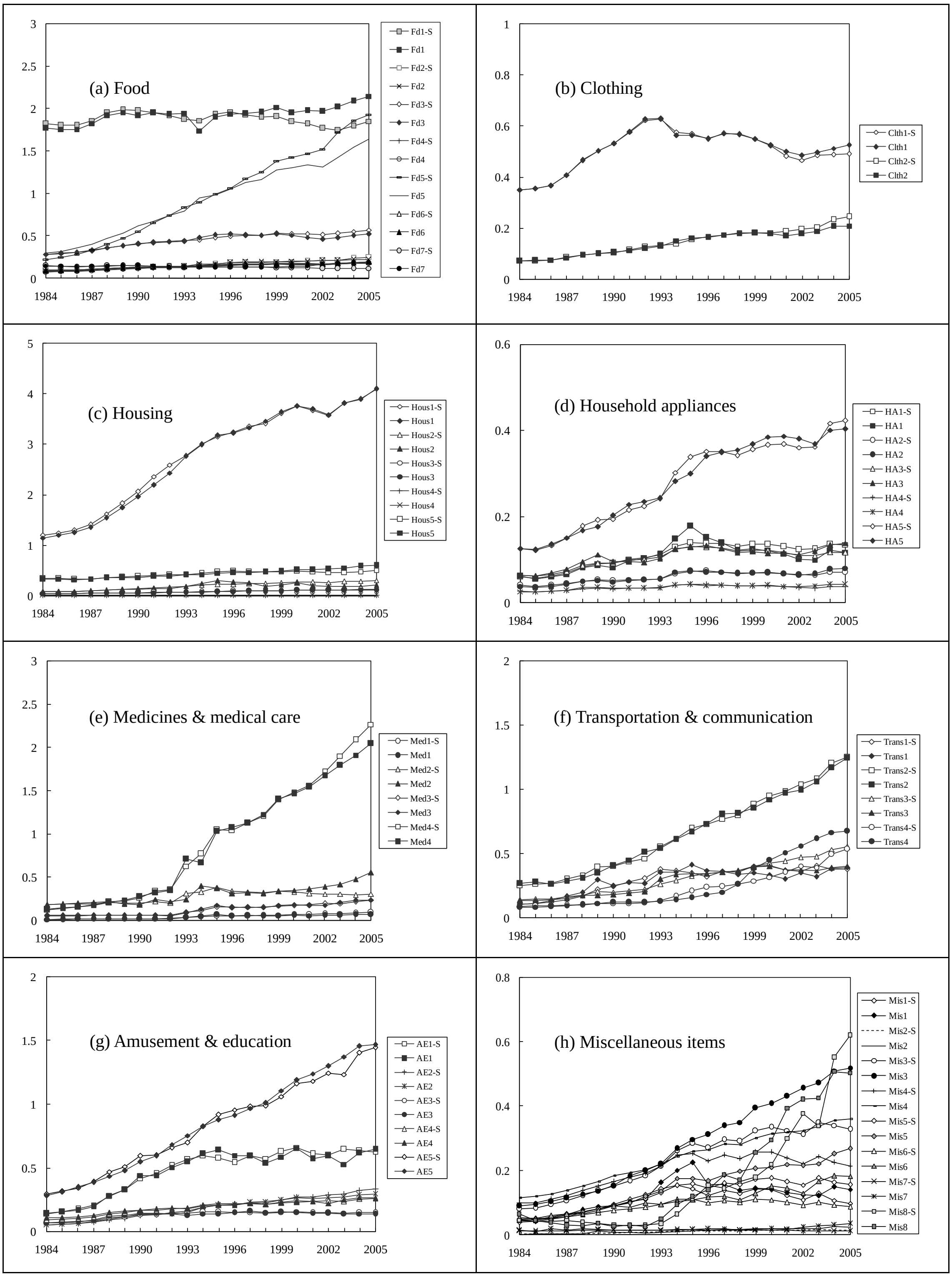

Fig. 5-12 Modeling results of the MNL model. (The horizontal axis denotes time (year); the vertical axis is the annual per capita consumption expenditure (10^4 NT\$)).

Note: a. The estimation period and ex-post forecast period denote the period of 1984-2003 and 2004-2005, respectively.

b. Subcategory's name attached with subtitle "-S" denotes the fitting value.

As for the statistical diagnose of the respective equation, multicollinearity is excluded since the *t* statistics of the estimators are significant. In addition, the insignificant LM statistics for heteroscedasticity are obtained in most equations, implying that the error terms can be considered homogenous. For most major subcategories, the high DW statistics infer that the serial correlation does not exist in these corresponding equations while some low DW statistics suggest that serial correlation problem may exist in some minor subcategories. Although heteroscedasticity errors occur in some equations to a slight extent, Long and Ervin (2000) suggested that the mild heteroscedasticity errors would not violate the OLS assumption on the normally distributed errors. Thus the models are still credible. The estimators of the parameters can be regarded as consistent and efficient ones.

Thus far, the consumer's behavior is well modeled by the variables associated with the changes in lifestyle. The established consumer's behavior model can be applied comprehensively with regards to the environmental concern. Subsequently the MSW discard model in terms of waste fractions is to be developed so as to couple with the consumption forecasting model and the consumer' behavior model set forth earlier.

5.4.1.3 The MSW Discard Model

The quantitative model for the MSW discard model is developed in four steps based on the principles of the econometric modeling mentioned in Chapter 3.1. The first step is to design a reasonable equation system for MSW fractions in light of the waste conversion process discussed in Chapter 2.4. Consumption expenditure on the related items and the influencing policy measures serve as the explanatory variables to model the amount of waste discards in terms of waste fractions. Subsequently the equations are to be statistically examined to find the optimal combination of the explanatory variables in each equation.

Table 5-15 presents the definition of the variables used in the model development. As for the policy variables, three major policy measures are represented by dummy variables to analyze the effectiveness of individual policy measures. Besides, a continuous variable, the recycling rate for all the waste fractions, is also considered as one candidate of the policy variable since it aggregated all the effects of policy interventions and the increasing environmental consciousness of the citizens. The incineration rate for all the waste fractions within the MSW discards, $Inci_t$, is used as a policy variable as well. The higher incineration rate implies that the separation should be launched more rigorously, and also indirectly indicates the extent of governmental efforts towards public environmental education for recycling activities in order to sustain good performance of incinerators. The historical trends of the recycling rate and the incineration rate are depicted earlier in Fig. 5-6.

Table 5-15 Description of variables used in the MSW discard model development.

Variable	Description	Unit
$WE_{m,t}$	Annual per capita MSW discards by eight categories in year *t*. *m* = paper, plastics, food, moisture, miscellaneous combustible items (abbreviated as 'mis-c'), metal, glass, and miscellaneous incombustible items (abbreviated as 'mis-inc').	kg
$Cons_t$	Annual per capita consumption expenditure on "food" and "amusement & education", respectively, in year *t*.	10^4 NT$ at 2001 prices
Fd_t, AE_t	Annual per capita consumption expenditure on "food" and "amusement & education", respectively, in year *t*.	10^4 NT$ at 2001 prices
FAE_t	The summation of Fd_t ("food") and AE_t ("amusement & education") in year *t*.	10^4 NT$ at 2001 prices
$Fd_{j,t}$	Annual per capita consumption expenditure on subcategory *j* of "food" in year *t*.	10^4 NT$ at 2001 prices
$HA_{j,t}$	Annual per capita consumption expenditure on subcategory *j* of "household appliance" in year *t*.	10^4 NT$ at 2001 prices
FHA_t	The summation of $Fd_{4,t}$ ("miscellaneous food commodity"), $Fd_{6,t}$ ("beverages"), $HA_{1,t}$ ("furniture") , and $HA_{3,t}$ ("household durable equipment") in year *t*.	10^4 NT$ at 2001 prices
Dum_1	Dummy variable for the "Resource Recycling Four-in-One Project" action; before 1997, the value is zero and 1 otherwise.	none
Dum_2	Dummy variable for the "Restrictions on the Use of Plastic Bags" action; before 2001, the value is zero and 1 otherwise.	none
Dum_3	Dummy variable for the "Mandatory Household Classification and Food Waste Recycling" action imposed in Taipei city; before 2003, the value is zero and 1 otherwise.	none
$Inci_t$	The portion of MSW discards treated by incinerators in year *t*, a continuous variable.	%
$Recy_t$	The recycled portion of MSW generation in year *t*, a continuous variable.	%

Note: a. Detail classification of consumption expenditure by category and subcategory is described in table 5-4.

b. Considering policy measures would be executed one year previously for some example area, the setting of validating dummy variables are one-year ahead of the formally bulletined year.

However, some policy measures such as “Keep Trash off the Ground”, “MSW Treatment Fee Charged by Collection Bags”, and “Decrease of MSW Collection Frequency” effectively reduce the amount of MSW discards (TEPA, 2008a). But the effects of these measures are difficult to be accounted in a country-level model while they are not simultaneously implemented throughout the island.

Taking paper waste for example, the individual’s consumption expenditure on “book, newspapers and periodicals” can be regarded as an important factor increasing the discards of paper waste based on the waste conversion process. Meanwhile, the discrete dummy variable associated with the recycling measures on paper waste (Dum_1) may have a negative impact on the discards of paper waste since the citizens’ environmental awareness is enhanced and the recycled paper is increased by the policy measures. Also, a continuous variable, the overall recycling rate ($Recy_t$), is related to the discards of paper waste. Hence, abovementioned variables which have potential casual relationships with the discards of paper waste can be used and tested in the development of the model of paper waste discards. Based on this concept, equations of respective waste fractions can be established.

The second step is to divide the datasets into two periods: the first is the estimation period, in which the quantitative relationships among the variables are to be defined (1992-2004); the second is the ex-post forecast period, in which the model prediction is tested (2005 -2006).

The third step is to choose an appropriate modeling approach for solving the equation system by using the dataset during the estimation period and decide the model of final decision. At the beginning, each equation of the equation system is established through single-equation models estimated by the OLS method. Next, the equation system is constructed as the SES model and estimated by the SUR method. Results from the two approaches would be compared. Both the OLS and SUR estimation are accomplished with the statistical software TSP® 5.0.

In the beginning of the estimation, the single-equation models for MSW fractions equations are estimated by using the OLS method based on the statistical assumptions described in Chapter 3.1. In order to construct the models in terms of statistical significance, some expenditure items are merged rationally and tested statistically to prevent the model from being influenced by the multicollinearity among the explanatory variables through checking the significances of the parameters. Meanwhile, each equation is examined statistically to confirm the BLU estimators. Table 5-16 indicates the specific explanatory variables used for each MSW fraction. Table 5-17 reports the OLS estimators and regression diagnosis. Most of the OLS estimators of the parameters are statistically significant at 5% confidence level or better. In addition, significant estimators of parameters (with significant *t* values and rational signs) by the OLS estimation clarify the influencing factors in each equation of waste fraction. However, as mentioned in Section 3, the factors of uncertainty in the waste conversion process (e.g., the life span and the utilization way of the commodities, etc.) lower the accuracy of the estimation food waste and glass waste (with low adjusted R^2 values). Besides, the potential intrinsic correlations among waste fractions are not considered in the OLS estimation. Thus, an attempt of performing the SES modeling is to be made for improving the modeling results.

Table 5-16 Description of explanatory variables used in each equation for MSW fractions.

Equation for MSW fractions	Explanatory variable	
	Consumption variable	Policy variable
Paper	AE_t	$Recy_t$ and Dum_1
Plastics	FAE_t	$Inci_t$ and Dum_2
Food	Fd_t	$Inci_t$ and Dum_3
Moisture	Fd_t	$Inci_t$ and $Recy_t$
Metal	FHA_t	$Inci_t$
Glass	FHA_t	$Inci_t$
Miscellaneous Combustibles	$Cons_t$	$Recy_t$ and Dum_1
Miscellaneous Incombustibles	FHA_t	$Recy_t$ and Dum_1

Table 5-17 Results of the single-equation models for MSW fractions estimated by the OLS method.

Explanatory variables		Explained variables (MSW fractions)							
		$WE_{paper,t}$	$WE_{plastics,t}$	$WE_{food,t}$	$WE_{moisture,t}$	$WE_{metal,t}$	$WE_{glass,t}$	$WE_{mis\text{-}c,t}$	$WE_{mis\text{-}inc,t}$
Consumption variable	AE_t	30.805 (17.35**)	--	--	--	--	--	--	--
	FAE_t	--	7.130 (22.43**)	--	--	--	--	--	--
	Fd_t	--	--	11.965 (13.79**)	55.193 (27.31**)	--	--	--	--
	FHA_t	--	--	--	--	25.101 (15.51**)	24.206 (10.40**)	--	10.336 (10.89**)
	$Cons_t$	--	--	--	--	--	--	1.914 (18.17**)	--
Policy variable	Dum_1	-4.729 (-0.84)	--	--	--	--	--	-5.321 (-2.09)	-1.991 (-2.40*)
	Dum_2	--	-11.438 (-2.39*)	--	--	--	--	--	--
	Dum_3	--	--	-3.743 (-0.50)	--	--	--	--	--
	$Inci_t$	--	-0.171 (-1.78)	-0.254 (-2.15)	-1.359 (-2.92*)	-0.167 (-7.22**)	-0.121 (-3.63**)	--	--
	$Recy_t$	-2.126 (-5.85**)	--	--	-1.225 (-0.79)	--	--	-0.973 (-5.96**)	-0.134 (-2.39*)
LM heter.		0.002	0.54	2.86	1.16	1.19	0.08	0.42	3.16
DW statistic		1.20	2.09	2.45	1.82	1.67	1.65	1.79	1.78
MAPE (%)		10.50	6.81	11.22	5.75	16.27	17.20	11.82	25.98
Adjusted R^2		0.582	0.763	0.087	0.768	0.788	0.399	0.700	0.676

Note: a. Values in the parentheses denote the *t* value.

b. * and ** denote significance at the 5% and 1% levels, respectively.

c. LM heter. denotes the LM statistic for heteroscedasticity.

Subsequently, the equation system is solved through the SES modeling approach. The SES model is initially examined based on the criteria of identification condition. Exogenous variables comprise 5 consumption variables and 5 policy variables without using any lagged endogenous variable, so the total number of exogenous variables is 10; meanwhile, 8 endogenous variables of MSW fractions are included in the SES model.

Each equation is then tested for the identification condition, and the results are shown in Table 5-18. All the equations are satisfied with the identification condition (over-identified) so that the SES model can be estimated. Next, the SES model is estimated by the SUR method, and the results are reported in Table 5-19.

Table 5-18 Diagnosis of Identification for the SES model in terms of MSW fractions.

Equation of MSW fractions	G	K	G^*	K^*	$G^*+K^*>G-1$	Identification status
Paper	8	10	7	7	○	over-identified
Plastics	8	10	7	7	○	over-identified
Food	8	10	7	7	○	over-identified
Moisture	8	10	7	7	○	over-identified
Metal	8	10	7	8	○	over-identified
Glass	8	10	7	8	○	over-identified
Miscellaneous Combustibles	8	10	7	7	○	over-identified
Miscellaneous Incombustibles	8	10	7	7	○	over-identified

Table 5-19 Results of the SES model for MSW fractions estimated by the SUR method.

Exogenous variables		Endogenous variables (MSW fractions)							
		$WE_{paper,t}$	$WE_{plastics,t}$	$WE_{food,t}$	$WE_{moisture,t}$	$WE_{metal,t}$	$WE_{glass,t}$	$WE_{mis\text{-}c,t}$	$WE_{mis\text{-}inc,t}$
Consumption variable	AE_t	30.751 (23.70**)	--	--	--	--	--	--	--
	FAE_t	--	7.228 (32.45**)	--	--	--	--	--	--
	Fd_t	--	--	12.100 (17.24**)	55.255 (41.37**)	--	--	--	--
	FHA_t	--	--	--	--	25.414 (17.36**)	24.830 (11.87**)	--	10.725 (15.31**)
	$Cons_t$	--	--	--	--	--	--	1.923 (25.72**)	--
Policy variable	Dum_1	-3.689 (-1.26)	--	--	--	--	--	-5.888 (-5.29**)	-2.679 (-5.96**)
	Dum_2	--	-10.517 (-6.26**)	--	--	--	--	--	--
	Dum_3	--	--	-1.556 (-0.43)	--	--	--	--	--
	$Inci_t$	--	-0.201 (-4.36**)	-0.287 (-3.53**)	-1.358 (-6.02**)	-0.173 (-8.27**)	-0.132 (-4.42**)	--	--
	$Recy_t$	-2.205 (-7.79**)	--	--	-1.255 (-1.67)	--	--	-0.932 (-8.15**)	-0.096 (-2.41*)
LM heter.		0.01	0.80	2.06	0.23	1.28	0.24	1.05	1.68
DW statistic		1.20	2.17	2.44	1.85	1.68	1.66	1.91	1.61
MAPE (%)		10.59	6.76	10.70	5.73	16.58	17.42	11.69	31.53
Adjusted R^2		0.679	0.817	0.294	0.823	0.824	0.507	0.768	0.732

Note: a. Values in the parentheses denote the t value.

b. * and ** denote significance at the 5% and 1% levels, respectively.

c. LM heter. denotes the LM statistic for heteroscedasticity.

Estimation results in Table 5-17 and Table 5-19 are statistically examined and compared based on the statistical criteria. After the trials for selecting appropriate explanatory variables in each equation, all the parameters have rational signs in both single-equation models and the SES model in the designed equations; besides, both models generate estimates in terms of waste fractions with acceptable biases. The LM test is applied to diagnose the heteroscedasticity error problem, and the insignificant LM statistics in the equations suggest that the homoscedasticity errors exist in the equations for both models. Theoretically, the GLS estimation adopted in the SUR method eliminates the heteroscedasticity error problem superior to the OLS method; however, the empirical results on the LM test of the two models are not significantly different due to the limited database. Meanwhile, the DW tests exclude the serial correlation in both models, and the results are also close to each other in the two models. However, the SES model provides more convincing estimators of the parameters (with more convincing *t* values) than those estimated by the OLS method. Furthermore, the "goodness-of-fit" of the equations (the adjusted R^2) are improved for all the equations in the SES model, especially the equation of food waste. Thus, estimating MSW fractions by the SES model is statistically better than estimating by the single-equation model, implying that the intrinsic correlations among waste fractions should be further considered. Consequently, the estimators in the SES model can be considered as consistent and unbiased ones to be adopted as the final results.

The fourth step is to validate the SES model. The estimation accuracy indicator (MAPE) is measured for both estimation period (1992-2004) and ex-post forecast period (2005-2006). Since the survey method of waste composition changed in 2004, dry-basis data of MSW fractions is unavailable after 2004. Thus, verification for ex-post forecasting is executed by estimating per capita overall MSW discards, which can be obtained by adding the estimates of individual waste fractions. The verification results for per capita waste discards by fraction and per capita overall MSW discards is shown in Table 5-19 and Table 5-20, respectively. The small values of MAPE during both estimation and ex-post forecast period imply that the SES model not only is capable of quantifying the relationships among the explanatory variables and MSW discards but also provides reliable projections for waste fractions. Afterward, Fig. 5-13 plots the model fitting series and the true values of the MSW discards by fraction, and Fig. 5-14 shows the results of the annual per capita overall MSW discards. Apparently, major trends can be modeled with the consumption and policy variables in light of the waste conversion processes. Still, some episode peak are not fit well, this may be due to (a) the credibility of the original waste statistics, (b) the missing explanatory variables, and (c) inappropriate model formulation. However, the outcomes from the linear model formulation by the SES model generate statistically confident estimators and estimates, and most of them achieve a high level of accuracy.

Table 5-20 Model verification for the SES model for per capita MSW discards.

Aggregate per capita MSW discards		MAPE (%)
Estimation period	(1992-2004)	2.48
Ex-post forecast period	(2005-2006)	3.04

Fig. 5-13 quantitatively demonstrates the interaction among waste discards, consumption, and MSW policies. Initially, discards of MSW fractions increased as the consumption expenditure increased, and subsequently, it diminished after the implementation of MSW policy measures. Moreover, in Fig. 5-13, the estimates of paper waste and the miscellaneous combustibles slumped during the ex-post period due to the rapidly increasing recycling rate (for all the waste fractions). As shown in Fig. 5-7, the recycling rate is promoted from 0.16% in 1997 to 34.97% in 2006. Even, the recycling rate is to be promoted to 50% in 2011 according to the national environmental policy (TEPA, 1998). Thus, much less discards of paper waste and miscellaneous combustibles can be expected without significant increases in the corresponding items of consumption expenditure. However, the discards of other waste fractions may drop slightly due to the small rise of corresponding consumption expenditures.

After statistically validating the MSW discard model, the outcomes are important for the MSW management system. The MSW discard model not only provides the quantitative descriptions of the waste conversion process but also serves as an estimation tool.

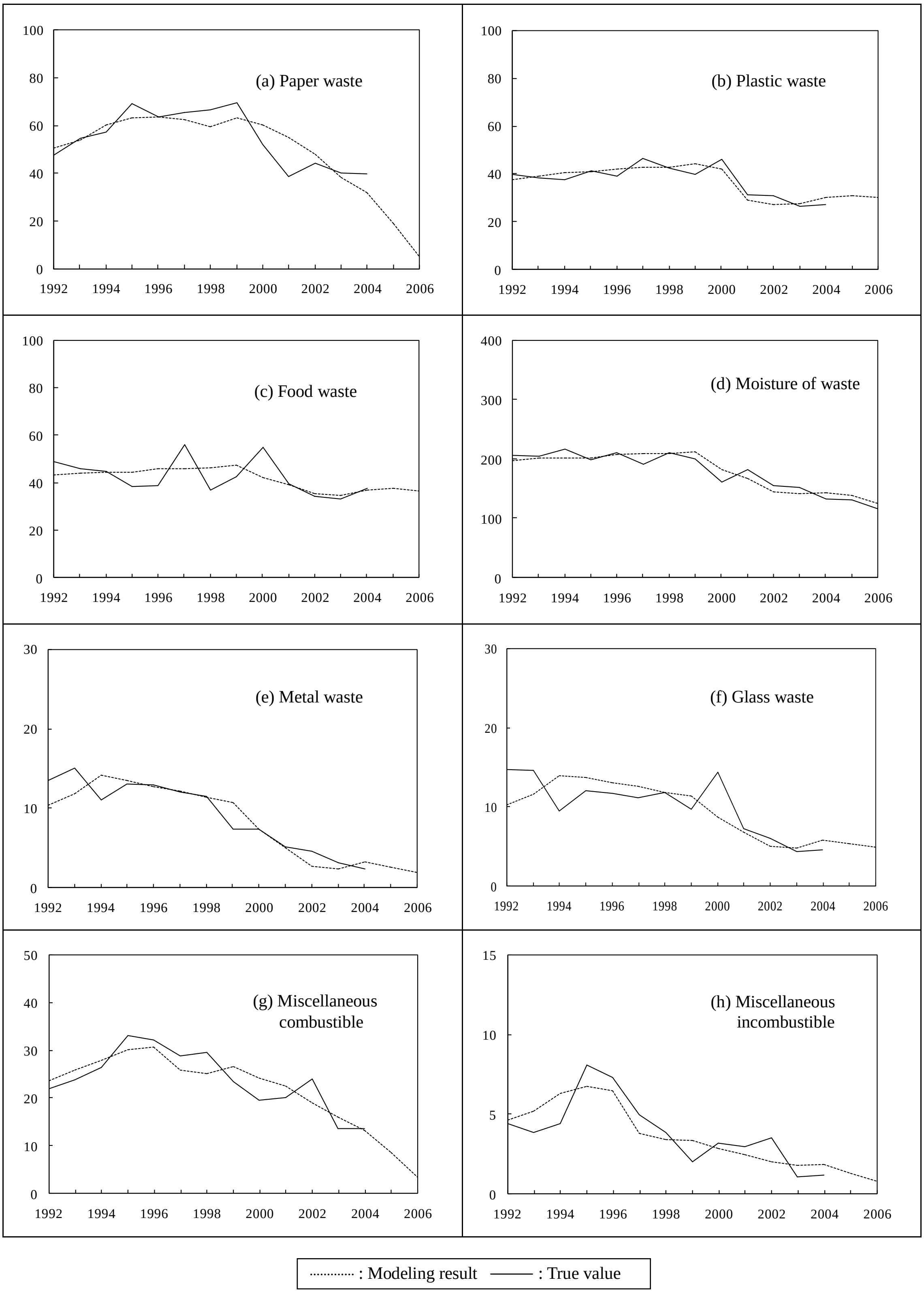

Fig. 5-13 Model fitting results of the SES model for MSW discards by waste fraction. (The horizontal axis denotes time (year); the vertical axis is the annual per capita MSW discards (kg)).

Note: a. The estimation and the ex-post forecast period denote the period of 1992-2004, and 2005-2006, respectively.

b. Since the method of MSW composition analysis changed based on a wet basis since 2005, there are no official records for dry-basis MSW composition data during the ex-post forecast period.

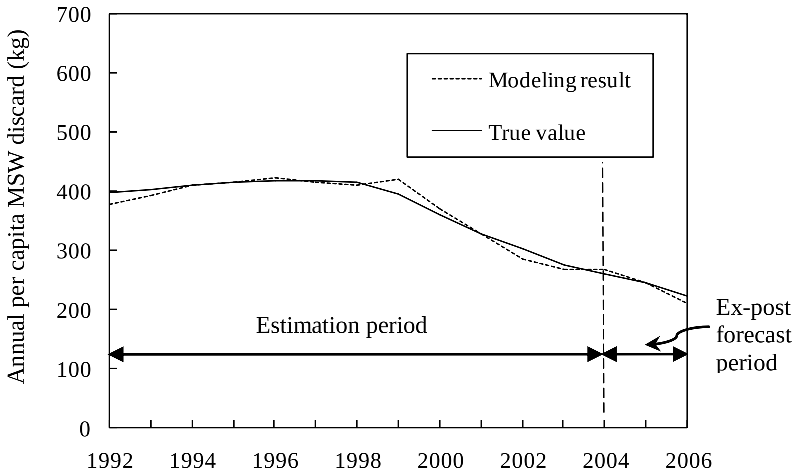

Fig. 5-14 Model fitting results of overall annual per capita MSW discards by the SES model.

In the linear regression model, the coefficient of the explanatory variable denotes the marginal effect of the variable on the explained variable; thus, the quantitative effects of specific consumption expenditure on the corresponding waste discards can be clearly found in the equations. The marginal effect designates the change of the explained variable after the change by 1 unit on the explanatory variable. Therefore, the coefficients of the explanatory variables have important implications. For the explanatory variables of consumption expenditure, the unit of the parameter is "kg waste per 10^4 NT$ per year", implying how much waste would be increased or decreased annually if the annual per capita consumption expenditure of a specific category or subcategory increase by 10^4 NT$; for the dummy variables of policy measures, the unit of the parameters is "kg waste per year", indicating how much waste would be increased or decreased annually if the policy measure is activated; for the continuous variables of policy measures, i.e., the recycling rate and the incineration rate, the unit of the parameters is "kg waste per 1% change of the policy variable", indicating how much waste would be increased or decreased annually if the policy variable increases by 1%.

Statistically significant and positive signs of the consumption variables prove the fact that consumption signifies the discards of waste fractions. Examining the equations in Table 5-19, the results show that the individual's consumption expenditures on "food", "household appliances", and "amusement & education" apparently enlarge the discards for almost all the waste fractions. Therefore, efficient waste reduction can be achieved if potential excess consumption is eliminated. As for the paper waste, the consumption expenditure on “amusement and education” (AE_t) is associated with the commodities and services generating the paper waste, such as the books, magazines, and the education expenses, etc. The modeling outcomes from the paper waste equation indicate that if an individual reduces 10^4 NT$ expenditure (at 2001 prices) on AE_t, such decrease on the consumption is associated with the decrease of the annual per capita discards of paper waste by 30.751 kg. Similar quantitative implications can be obtained in each equation in keeping with the concept of waste conversion process during the consumption.

On the basis of the relationships defined in the MSW discard model, the consumption on “amusement and education” is a driving factor of the discards of paper waste. One reason is that higher education has become popularized in recent decades. The number of annual graduate from universities and colleges increased by 225% during the period of 1991 to 2007 (TME, 2008). A more civilized society may consume more paper and generate more paper waste. Consumption on “food” and “amusement and education” is proved to enlarge the discards of plastic waste, implying the contemporary civilized lifestyle relies highly on the commodities made of plastics. Also, the quantitative results indicate that the discards of food waste and moisture content can be strongly related to the consumption expenditure on “food”. Besides, the discards of metal waste, glass waste, and waste of miscellaneous combustibles can be traced back to the consumption on several specific subcategories within “food” and “household appliances”, defined as “*Mis*” in Table 5-19, since these two materials are usually used to produce similar commodities. As for the miscellaneous combustibles, the overall per capita consumption is considered as the influencing factor since the sources of such waste fraction are complex in its conversion processes.

Using such information, policy makers of the national level can make policy incentives or impose regulations facilitating the unsustainable consumption and production. Besides, local municipalities should promote the environmental awareness of the citizens so as to reduce the waste discards and extend the operation period of the disposal sites. Meanwhile, consumers can find clues to regulate their consumption behavior and weigh up their expenditure on specific categories, which results in large waste discards. Furthermore, producers should rethink their responsibility, for example, to reduce unnecessary packaging materials, which may increase MSW discards on a specific waste fraction, during the production and transportation process of the goods. Besides, the life spans of such products should be prolonged in light of the concepts of "dematerialization", "slow consumption", etc., as previously mentioned in Chapter 2.2.

On the other hand, municipalities can find substantial policy implications based on the parameters of policy variables. Statistically significant and negative signs of policy variables imply that MSW policy interventions effectively reduce the discards of waste fractions, particularly on plastic waste and the moisture content of waste. The marginal effect of "Resource Recycling Four-in-One Project" (Dum_1) is significant to reduce MSW discards, particularly metal waste. Although the effect of Dum_1 is not always significant in every equation, this policy measure enhances fundamental works for resource recycling networks. The activation of Dum_1 is associated with the annual decreases of per capita discards of paper waste, the miscellaneous combustibles, and the miscellaneous incombustibles by 3.69 kg, 5.89 kg, and 2.68 kg, respectively. The results infer that the recycling programs have been inspired over this period, thus, the market mechanism should be induced to improve the recycling programs. An economically efficient recycling industry and market for recycled and reused materials should be promoted in the next stage. In addition, "Restrictions on the Use of Plastic Bags" (Dum_2) annually reduces 10.52 kg per capita of plastic waste discards, indicating that citizens have gradually changed their habits during the consumption. However, policy makers on the national level should propose the adequate substitutes of plastic bag and support sufficient administrative budget to local municipalities for the enforcement of relevant regulations. Although the "Mandatory Household Classification and Food Waste Recycling" (Dum_3) was launched only in the Taipei area from 2004 (extending to other areas soon), it reduces annual per capita food waste discards by 1.56 kg. From the environmental perspective, this action helps stabilizing the operation of incinerators since food waste usually has a high moisture content due to which much energy is inefficiently consumed in the incineration process. In addition, the recycling and reuse of organic waste, mainly contributed by food waste, is emphasized in terms of soil layer recovery for the ecological system (Marmo, 2008). Thus, an economically efficient recycling industry and market for recycled food waste should be further promoted.

Since incineration has been chosen as the main intermediate treatment technology for MSW, the incineration rate in MSW treatment ($Inci_t$) deeply affects MSW discards in five of eight categories, especially for the moisture content of waste. The higher incineration rate implies that more recyclable resource can be separated from those to be incinerated. Meanwhile, the local municipalities endeavored to the recycling programs in order to sustain the performance of the incinerators and to minimize the hazardous air pollutants emitted from incinerators. Although the incineration technology raises the risk of exposure to hazardous pollutants for the citizens who live nearby the incinerators, this transaction of waste intermediate treatment technology makes the public aware of MSW problems, and thus inspires both private and administrative recycling programs.

The recycling rate also significantly influences the discards of paper waste, moisture content of waste, as well as the miscellaneous of combustibles and incombustibles. Since the improvement of recycling rate is an important target of MSW management (TEPA, 1998), as abovementioned, the relevant recycling industry and market of reused materials should be developed. Efficient economic incentives, such as deposit fee of commodities and subsidy for the producers, should be proposed.

In fact, the outcomes of the MSW discard model indicate that all the policy measures significantly arouse the public concern about the waste problem. As for policy makers, relevant strategies can be further considered to improve the recycling rate as well as the existing MSW policies. Also, the changes in the future MSW discards can be evaluated based on the SES modeling approach set forth here.

5.4.2 Backcasting of the MSW Discards via the Estimation Model System

In keeping with the modeling philosophy based on the conversion process, estimating the discards of per capita waste fraction is possible at every point of time. Moreover, by adding up the discards of waste fractions, per capita overall MSW discards could be estimated.

As for the overall estimation model system, two approaches are proposed here in the backcasting of MSW discard to simulate the past condition of MSW discard:

(1) Approach-1: directly using the built MSW discard model given that required historical data of the explanatory variables.

    Based on the MSW discard model, the consumption terms and the policy variables serve as the exogenous variables in the first approach.

(2) Approach-2: using the overall estimation model system given that the historical data of the exogenous variables for the overall equations.

    To perform the overall estimation model system, at the beginning, the annual per capita consumption expenditure is modeled in the consumption forecasting model, with the macro socioeconomic variables. Subsequently, the estimated per capita consumption expenditure and socioeconomic variables are used as the explanatory variables to simulate the distribution hierarchically by using the consumer's behavior model, comprising the LES model and the MNL model. Consequently, the amount of discards in terms of MSW fractions can be estimated by using the consumption items modeled earlier and the MSW policy variables.

    Since per capita consumption expenditure and its distribution can be generated within the estimation model system, the socioeconomic variables, the annual per capita GDP and the policy variables are the exogenous variables, as shown in Table 5-21.

Both the approaches can provide a preliminary image of the past condition of the amount of MSW discards. However, the first approach is based on the MSW discard model while the second approach considers the overall estimation model system as shown in Fig. 3-1. Moreover, the difference of the two approaches is on the exogenous variables, which control the behavior of the MSW discards.

According to the available MSW composition data, the backcast period is assigned from 1981 to 1991, in which historical data of explanatory variables is used to model

Table 5-21. Description of the exogenous variables for the integrated estimation model system in Taiwan.

Indices		Description	Unit
Socioeconomic variables	$PGDP_t$	Per capita gross domestic product	10^4 NT$ at 2001 prices
	$Unemp_t$	The unemployment rate in the labor force in year *t*.	%
	$Hov65r_t$	The portion of the elder population (over 65 years) in the overall population	%
	$Saving_t$	The saving rate in the disposable expenditure in year *t*.	%
MSW policy variable	Dum_1	Dummy variable for the "Resource Recycling Four-in-One Project" action; before 1997, the value is zero and 1 otherwise.	none
	Dum_2	Dummy variable for the "Restrictions on the Use of Plastic Bags" action; before 2001, the value is zero and 1 otherwise.	none
	Dum_3	Dummy variable for the "Mandatory Household Classification and Food Waste Recycling" action imposed in Taipei city; before 2003, the value is zero and 1 otherwise.	none
	$Inci_t$	The portion of MSW discards treated by incinerators in year *t*, a continuous variable.	%
	$Recy_t$	The recycled portion of MSW generation in year *t*, a continuous variable.	%

the past trends of the discards of MSW fractions. The backcasting of MSW discards is to be performed by the two approaches earlier proposed, and the results would be compared.

Combining the outcomes generated in the earlier section, Fig. 5-15 and Fig. 5-16 depict the estimation results by the two approaches for the annual per capita MSW discards for the waste fractions and for the overall MSW discards, respectively. The figures integrate the estimates during the backcast, estimation, and ex-post forecast periods while the later are simulated in the earlier section so as to see the overall evolution of the MSW discards. Accordingly, the two approaches generate close estimates both in Fig. 5-15 and Fig. 5-16. Thus, the estimation model system is stable and reliable in the modeling for the backcast, estimation, and ex-ante forecast periods.

Since the respective MSW composition data is unavailable in the backcast period, a preliminary validation can be conducted by the limited overall MSW discard data. In Fig. 5-15, the backcasting for past waste fractions seems to produce overestimates of per capita overall MSW discards from 1987 to 1991. One reason is that recycling activities by private sectors, e.g. recycling by the scavengers, private companies, or non-governmental organizations (NGOs), were not officially documented so that this factor cannot be considered in the modeling work.

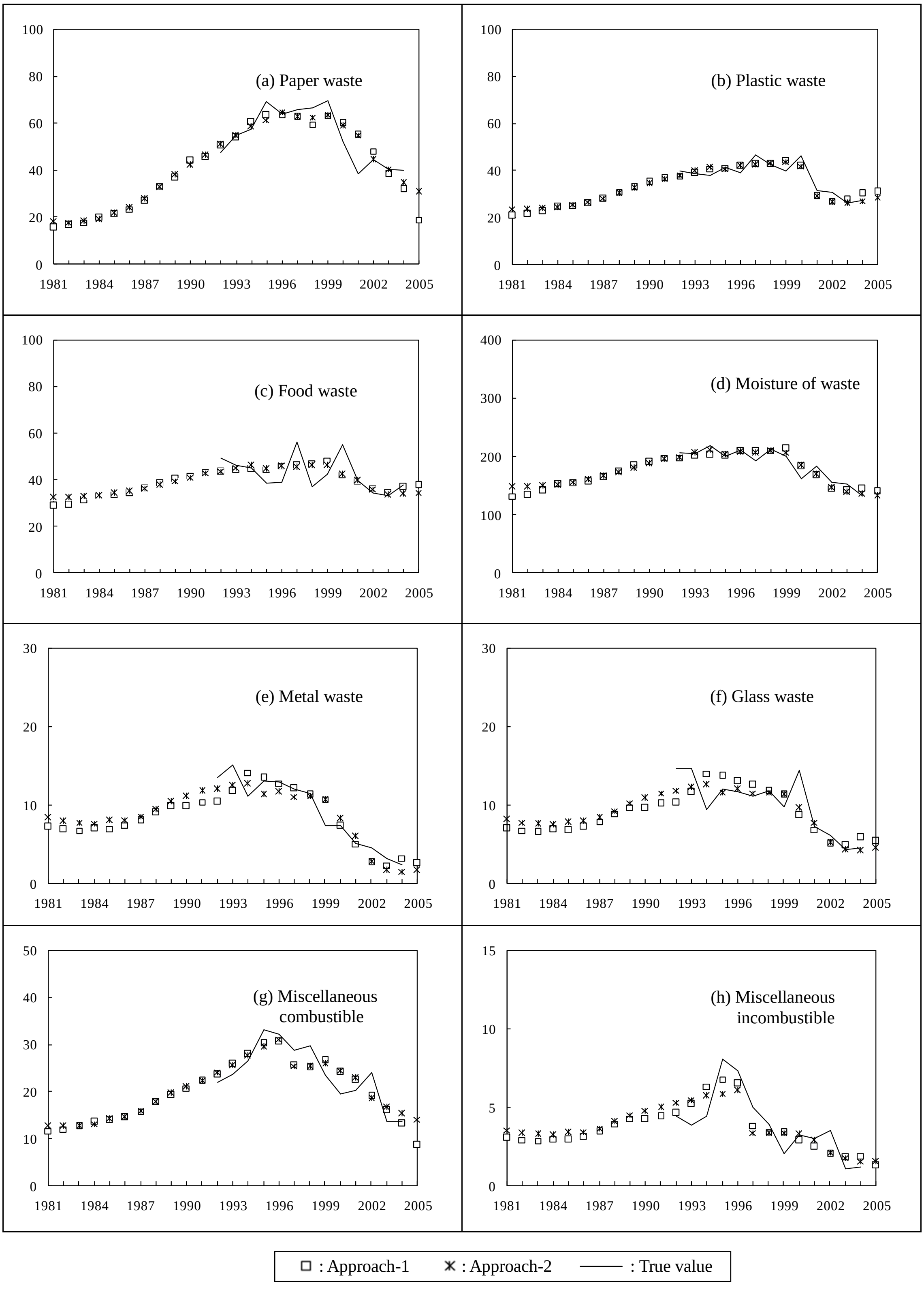

Fig. 5-15 Backcasting as well as the estimation of the MSW discards by waste fraction. (The horizontal axis denotes time (year); the vertical axis is the annual per capita MSW discards (kg)).

Note: a. The backcast, estimation period, and ex-post forecast period denote the period of 1981-1991, 1992-2004, and 2005-2006, respectively, based on the official MSW composition data.

b. Since the method of MSW composition analysis changed based on a wet basis since 2005, there are no official records for dry-basis MSW composition data during the ex-post forecast period.

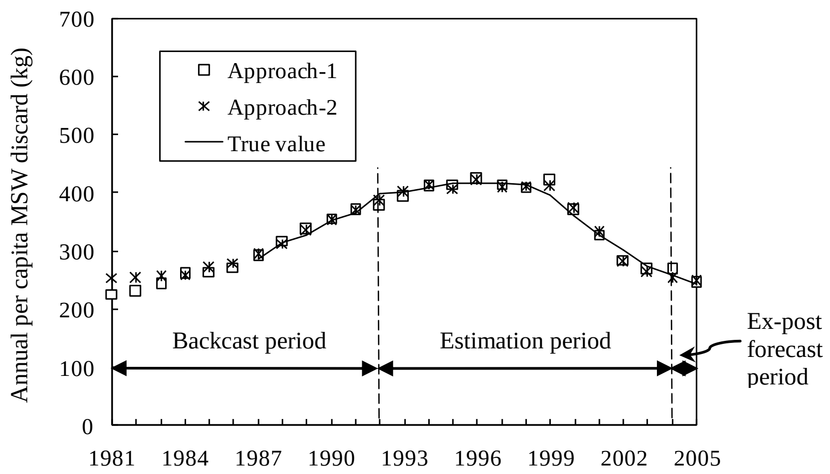

Fig. 5-16 Model fitting results of overall annual per capita MSW discards by the estimation model system.

Note: The backcasting period (1981-1991), estimation period (1992-2004), and ex-post period (2005) is identified based on the official MSW composition data while the official records of the overall per capita MSW discards has been reported since 1987.

5.4.3 Ex-ante Forecasting of the MSW Discards via the Estimation Model System

Despite the backcasting, by coupling the models, the estimation model system can serve as an ex-ante forecasting tool. Thus, the impact of the consumption and lifestyle changes on the MSW discards can be analyzed through the models. Since the consumption variables can be estimated within the estimation model system, for the overall integrated model system, the socioeconomic indices and the MSW policy measures serve as the exogenous variables, which are wholly determined by the outside systems. Thus a future projection of MSW discards can be achieved with the projections of the exogenous variables.

Namely, the projections of the exogenous variables can be estimated by other models established independently by other studies or by using the policy target values as well as the rational scenarios. As shown in Table 5-21, the exogenous variables for the overall estimation model system are the socioeconomic variables in terms of the lifestyle changes and the MSW policy variables.

In this study, the ex-ante forecasting of the MSW discards is accomplished by the scenario analysis with the estimation model system set forth earlier. For the ex-ante forecasting of MSW discards by waste fraction, three scenarios are assumed for the period from 2006 to 2021, which designates the 110th year of the “Republic Era”.

The elder population ratio ($Hov65r_t$) is forecasted by the domestic report with an increasing trend (TCEPD, 2008). Besides, the setting of the MSW policy variables will follow the target values of the national environmental plan as presented in Table 5-7. Other parameters are assumed on the basis of the past trends of the series. Fig. 5-17 demonstrates the historical trends of the three socioeconomic variables associated with the required exogenous variables in the ex-ante forecasting, and Table 5-22 shows their statistical properties in the recent years. According to their behavior in the recent decade, the rational evolution of them would be assumed in the scenarios.

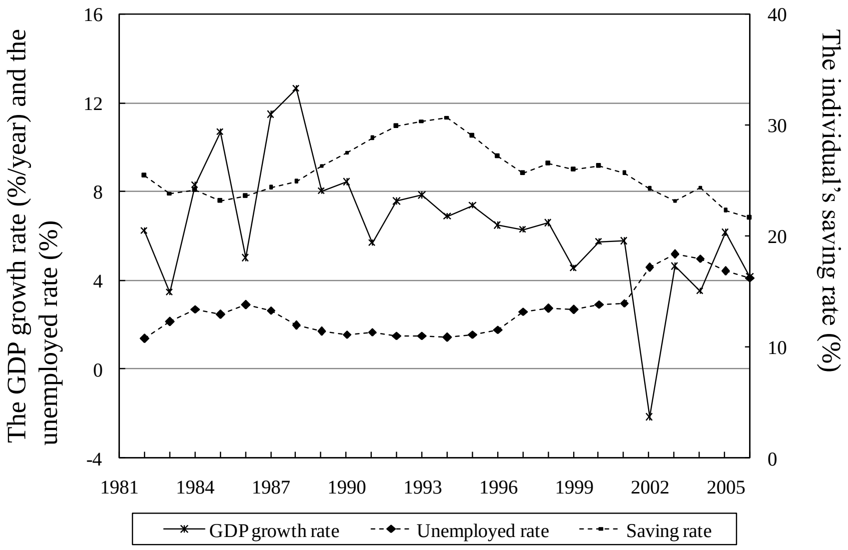

Fig. 5-17 Historical trend of the GDP growth rate, the unemployed rate as well as the individual’s saving rate in Taiwan: 1981-2005.

Note: The left-hand-side vertical axis corresponds to the GDP growth rate, the unemployed rate while the right-hand-side axis corresponds to the saving rate.

Table 5-22 Basic descriptive statistics of the GDP growth rate, the unemployed rate as well as the individual’s saving rate in Taiwan: 1997-2005.

Indicator / Basic statistics	GDP growth rate (%)	Unemployed rate (%)	Saving rate (%)
Maximum	6.59	5.17	26.52
Mean	4.52	3.72	24.59
Minimum	-2.17	2.60	21.63
Standard deviation	2.49	0.96	1.87

The scenarios are designed in keeping with the purpose of this study for analyzing the impact of the consumption, which is driven by the lifestyle changes, on the MSW discards, so that the ex-ante forecasting of the MSW discards can be of importance for regulating the consumer's behavior and designing the MSW management system. The three scenarios are designed to forecast the reasonable potential changes of the socioeconomic environment in terms of the lifestyle changes and its impact on the consumption as well as, ultimately, on the MSW discards. In this study, the scenarios for the business as usual (BAU), the high consumption society, and the low consumption society, are assumed as follow:

Scenario A (BAU scenario): Per capita GDP is assumed to increase by 5% annually; the saving rate is kept on the same level as that of 2005, 21.63%; the unemployed rate is assumed at a moderate level, 4%; the elder population rate is set based on the national report (TCEPD, 2008); the MSW policy variables are set according to the national environmental plan, except that the incineration rate is kept in the same level of that of 2006, 82.76% (TEPA, 1998; TEPA, 2008c).

Scenario B (the low consumption scenario): Per capita GDP is assumed to increase by 3% annually (based on the lower level of historical trend); the saving rate is assumed to be on a higher level than that of 2005, 24%; the unemployed rate is assumed at a higher level, 5% (compared with the historical trend); the elder population rate is set based on the national report; the MSW policy variables are set according to the national environmental plan except that the incineration rate is kept in the same level of that of 2006, 82.76%.

Scenario C (the high consumption scenario): Per capita GDP is assumed to increase by 7% annually (based on the higher level of historical trend); the saving rate is assumed to be on a lower level than that of 2005, 21% (compared with the historical trend); the unemployed rate is assumed at a lower level, 2.5% (compared with the historical record); the elder population rate is set based on the national report; the MSW policy variables are set according to the national environmental plan except that the incineration rate is kept in the same level of that of 2006, 82.76%.

Conditions of these scenarios are summarized in Table 5-23, and Fig. 5-18 plots the assumed evolution for the elder population ratio and the recycling rate of overall waste discards. It should be noted that the recycling rate of the overall waste fractions is expected to be promoted from 27.23% (2006) up to 50% (2011) on the basis of the national environmental plan (TEPA, 1998); however, a conservative increase of this rate is set from 50 in 2011 up to 60 in 2021 in this study. Based on the assumed scenarios, the estimation model system draws the sequential outputs: (1) per capita consumption expenditure; (2) the distribution of per capita consumption expenditure among the categories and the subcategories; (3) per capita MSW discards by waste fraction. The forecasting is performed with the statistical software TSP® 5.0.

Table 5-23. Conditions in the future scenarios

Exogenous variable	Scenario		
	A	B	C
Consumption level	BAU	low	high
Growth rate of per capita GDP (%/year)	5	4	7
Saving rate, $Saving_t$ (%)	21.63	24	21
Unemployed rate, $Unemp_t$ (%)	4	4.5	2.5
Elder population rate, $Hov65r_t$ (%)	Increase progressively based on the nation projection (see Fig. 5-18).		
Recycled portion, $Recy_t$ (%)	Increase progressively from 30.2 (2007) to 50 (2011), and further to 60 during 2012 to 2021 (see Fig. 5-17).		
Incineration rate, $Inci_t$ (%)	82.76		
Dum_1, Dum_2 and Dum_3	The policy measures are activated in the three scenarios.		

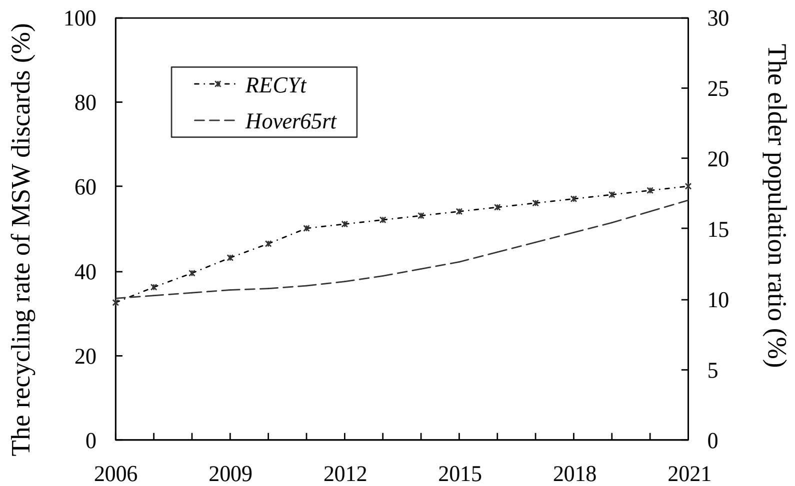

Fig. 5-18 The assumed values for the recycling rate of MSW discards and the elder population ratio in the scenario analysis.

Fig. 5-19 shows the ex-ante forecasting of per capita consumption expenditure under the three scenarios. Apparently, the ex-ante forecasts are increasing since the economic development are assumed to be improved upon, and the projections are always the largest in the high consumption scenario (Scenario C), mediate in the BAU scenario (Scenario A), and the smallest in the low consumption scenario (Scenario B) in accordance to the assumptions of the scenarios. In addition, per capita consumption expenditure for the Scenario A to C is to be increased by around 224%, 196%, and 290%, respectively, during 2005-2021 (16 years). Compared with the historical trend within the same duration, the annual per capita consumption expenditure have increased by 216% during 1989-2005, thus the results appear to be reasonable.

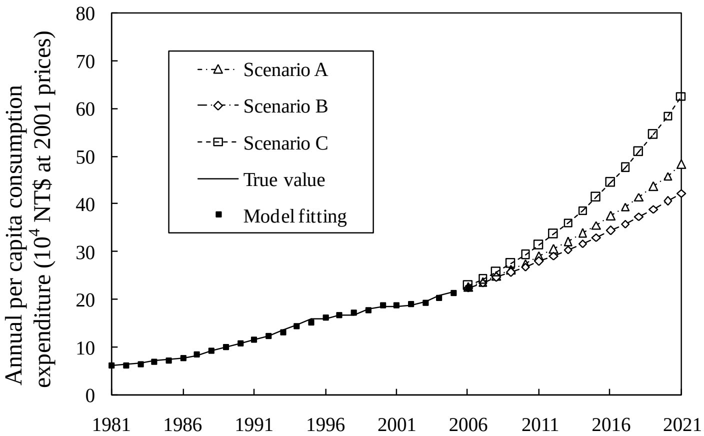

Fig. 5-19 Model fitting curves and the true value of the annual per capita consumption expenditure.

Note: The model fitting denotes the backcasts, the estimates, and the ex-post forecasts during 1981-2005 while the ex-ante forecast period denote the period of 2006-2021.

Next, the distribution of per capita consumption expenditure for the detailed categories and subcategories are forecasted by the consumer's behavior model based on the assumptions of the scenarios. Indeed, among the exogenous variables in the consumer's behavior model, the elder population ratio has a rapid change by 178% during the period. Meanwhile, the annual per capita consumption expenditure arises rapidly as projected in the previous stage. Thus, the ex-ante forecasting on the consumer's behavior can be seemed as the impact evaluation in terms of the aging phenomenon as well as the increasing consumption. The modeling results are represented in Fig. 5-20 and Fig. 5-21 for the distribution of the annual per capita consumption expenditure among the categories and subcategories.

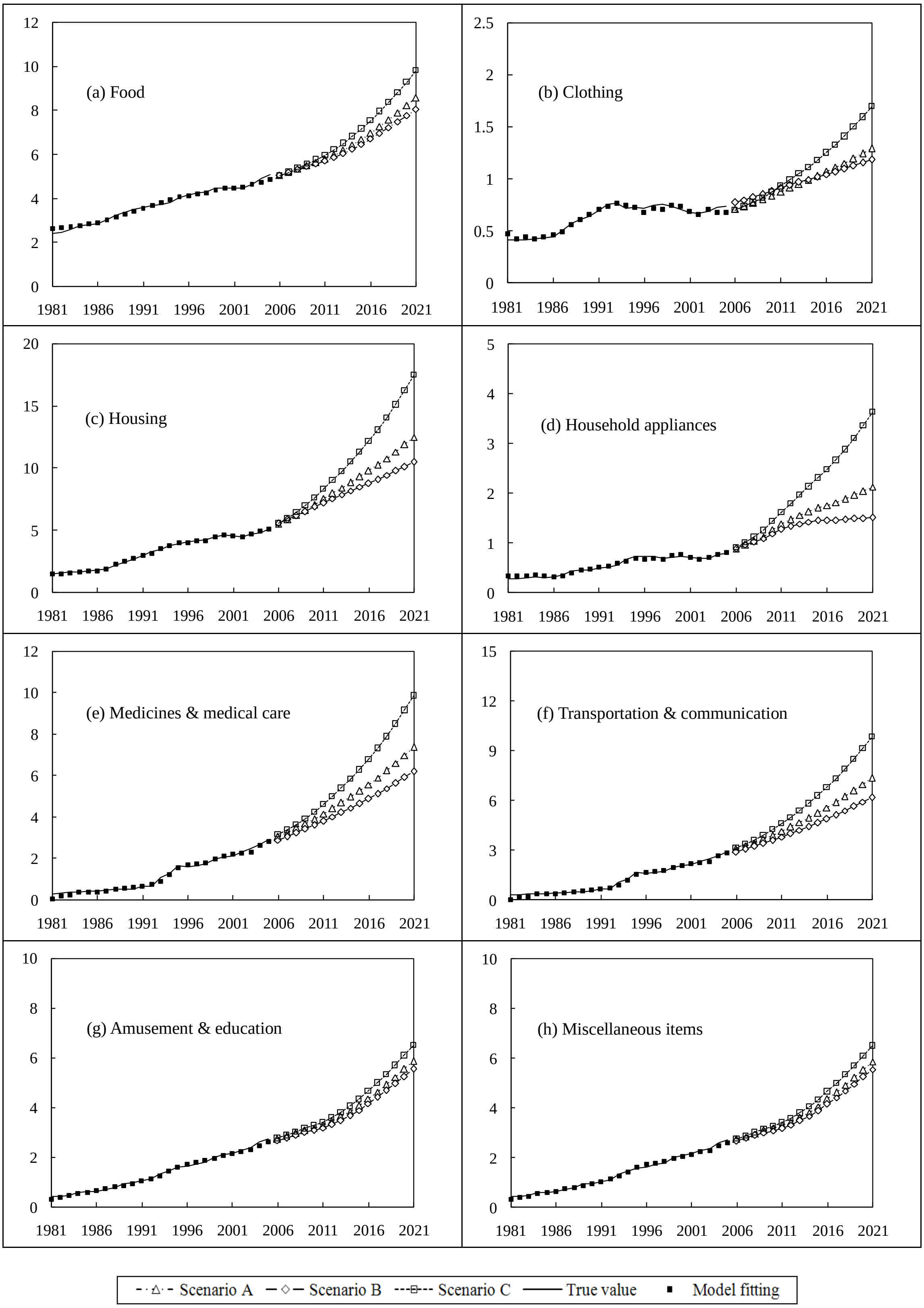

Fig. 5-20 Model fitting and ex-ante forecasting curves of per capita consumption expenditure by category.

Note: a. The horizontal axis denotes time (year); the vertical axis is the annual per capita consumption expenditure (104 NT$).

b. The model fitting denotes the backcasts, the estimates, and the ex-post forecasts during 1981-2005 while the ex-ante forecast period denote the period of 2006-2021.

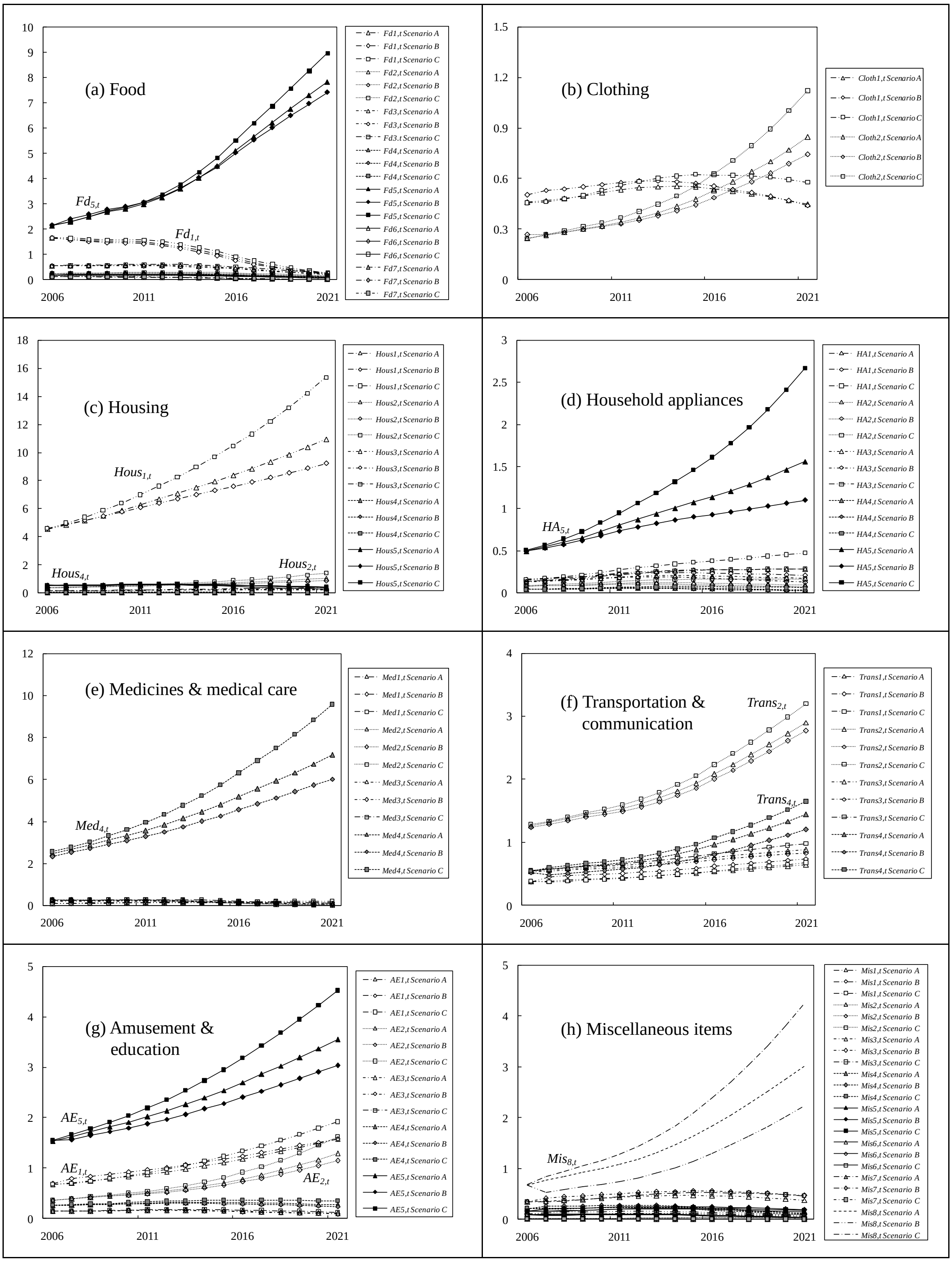

Fig. 5-21 Model fitting and ex-ante forecasting curves of the annual per capita consumption expenditure by subcategory.

Note: a. The horizontal axis denotes time (year); the vertical axis is the annual per capita consumption expenditure (10^4 NT\$).

b. The ex-ante forecast period denote the period of 2006-2021. Please refer to Fig. 5-12 for the results for model fitting.

In Fig. 5-20 and Fig. 5-21, the ex-ante forecasts of the consumption expenditures are also the largest in the high consumption scenario (Scenario C), mediate in the BAU scenario (Scenario A), and the smallest in the low consumption scenario (Scenario B).

In Fig. 5-20, it is apparent that all the consumption expenditures by categories are increasing due to the assumed socioeconomic condition, and are dominated by the marginal budget shares of the consumption categories estimated by the LES model (see Table 5-11). According to the future projections, in 2021, the ranking of quantity of the consumption expenditure among the categories are roughly (1) housing, (2) food, (3) medicines & medical care, (4) amusement & education, (5) transportation & communication, (6) miscellaneous items, (7) household appliances, and (8) clothing.

In addition, Table 5-24 represents the changes between the projected and true values of the series of interest. The consumer's preferences under different scenarios are clearly revealed in the ex-ante forecasting.

Table 5-24 Changes of the annual per capita consumption expenditure by category by the ex-ante forecasting: 2005-2021.

Category / Scenario	Fd_t	$Cloth_t$	$Hous_t$	HA_t	Med_t	$Trans_t$	AE_t	Mis_t
Scenario A	250.5	285.2	423.0	490.1	431.3	346.8	406.8	419.5
Scenario B	222.0	211.6	309.5	270.6	342.3	323.7	334.1	318.4
Scenario C	327.0	327.0	729.4	1088.0	699.8	419.9	599.6	699.7

As Fig. 5-21 illustrated, the consumption expenditures among detailed subcategories are changing with the changes of the assumed scenarios, which represents a society of increasing consumption and aging population. Furthermore, Table 5-25 reports the changes of the consumption expenditures by subcategories during 2005-2021. Indeed, all the consumption expenditures on the subcategories are increasing in accordance to the assumed scenarios.

For the "food" category, the "food from restaurant" ($Fd_{5,t}$) will occupy the largest portion and have a biggest increase among the subcategories of food over the period. On the other hand, the consumption expenditure on the main food materials ($Fd_{1,t}$), representing "eating at home" are almost at the same level.

Table 5-25 Changes of the annual per capita consumption expenditure by category by the ex-ante forecasting: 2005-2021.

Category	Subcategory		Changes (%)		
			Scenario A	Scenario B	Scenario C
Food (Fd_t)	Cereals and cereal products Meat and meat products	($Fd_{1,t}$)	10.74	9.41	12.56
	Milk and milk products	($Fd_{2,t}$)	6.02	51.26	70.08
	Fruits	($Fd_{3,t}$)	40.96	36.96	47.53
	Miscellaneous food commodity	($Fd_{4,t}$)	46.61	42.19	54.04
	Food from restaurant	($Fd_{5,t}$)	476.73	451.44	546.07
	Beverages	($Fd_{6,t}$)	35.21	31.27	41.03
	Tobacco and betel nut	($Fd_{7,t}$)	5.47	4.77	6.40
Clothing ($Cloth_t$)	Garments	($Cloth_{1,t}$)	85.17	83.70	109.63
	Footwear	($Cloth_{2,t}$)	404.61	356.08	536.32
Housing ($House_t$)	Residential rent	($House_{1,t}$)	265.78	223.92	373.62
	Maintenance and repairs	($House_{2,t}$)	474.47	397.27	662.85
	Water supply	($House_{3,t}$)	217.30	166.19	277.28
	Facility insurance fee	($House_{4,t}$)	25.81	19.92	33.23
	Electricity and gas supply	($House_{5,t}$)	54.79	42.87	67.24
Household appliances (HA_t)	Furniture	($HA_{1,t}$)	238.16	175.56	402.65
	Fabric products	($HA_{2,t}$)	114.63	80.23	196.49
	Household durable equipment	($HA_{3,t}$)	120.86	88.51	204.69
	Tableware and other utensils	($HA_{4,t}$)	81.13	57.93	138.33
	Housekeeping services	($HA_{5,t}$)	386.06	271.82	660.70
Medicines & medical care (Med_t)	Medical supplies and appliances (including the fee of the clinics)	($Med_{1,t}$)	210.99	177.31	277.52
	Medical equipment and supplement	($Med_{2,t}$)	5.36	4.59	7.02
	Medicines and health food	($Med_{3,t}$)	34.58	26.09	46.80
	Health insurance	($Med_{4,t}$)	328.78	278.87	431.38
Transportation & communication ($Trans_t$)	Transportation and communication equipment	($Trans_{1,t}$)	159.91	184.38	166.75
	Maintenance and repair charge of transportation equipment	($Trans_{2,t}$)	219.44	209.95	240.45
	Transportation fees and insurance	($Trans_{3,t}$)	214.66	202.04	236.24
	Communication services	($Trans_{4,t}$)	198.84	166.43	225.76
Amusement & education (AE_t)	Traveling expenses	($AE_{1,t}$)	244.01	245.85	297.65
	Entertainment expenses	($AE_{2,t}$)	445.13	396.84	560.93
	Book, newspapers and periodicals	($AE_{3,t}$)	73.79	67.81	92.24
	Entertainment equipment	($AE_{4,t}$)	105.21	92.60	133.03
	Educational expenses	($AE_{5,t}$)	241.14	206.17	307.27
Miscellaneous items (Mis_t)	Miscellaneous commodities	($Mis_{1,t}$)	56.32	81.44	66.17
	Financial services	($Mis_{2,t}$)	204.89	276.09	245.24
	Cosmetic items	($Mis_{3,t}$)	97.06	120.37	118.77
	Hair cutting and shower	($Mis_{4,t}$)	34.27	43.71	41.63
	Personal care services	($Mis_{5,t}$)	71.26	92.52	86.14
	Wedding and funeral expenses (excluding of food charges)	($Mis_{6,t}$)	23.05	29.59	27.95
	Miscellaneous expenses	($Mis_{7,t}$)	4.83	5.76	5.97
	Other non-saving insurance expenses	($Mis_{8,t}$)	800.23	591.17	1123.80

For the “clothing” category, the consumption on “garments” ($Cloth_{1,t}$) is still increasing; however, the consumption on footwear ($Cloth_{2,t}$) appear to be on a constant level.

For the “housing” category, the consumption on “resident rent” ($Hous_{1,t}$) will occupy the highest portion. The reason may be due to the increases of the small-scale households and the decreases of the number of the persons per household, which are showed as the SF_t and $Hpop_t$ in Table 5-2 and Fig. 5-3. Meanwhile, the consumption on “maintenance and repair” ($Hous_{2,t}$) is to be increasing so that it will prevail over the consumption on “electricity and gas supply” ($Hous_{5,t}$) in the aging society.

For the “household appliances” category, the “housekeeping service” is the leading item. However, significant changes do not appear on the consumption on “household durable equipment” ($HA_{3,t}$) and “tableware and other utensils” ($HA_{4,t}$), which are associated with the MSW discards.

For the “medicines and medical care” category, the “health insurance” ($Med_{4,t}$) is still the leading item and with the biggest changes among the subcategories. Besides, the rapidly increasing consumption on “medical supplies and appliances” ($Med_{1,t}$) implies that the individuals will pay more on health care in the aging society.

For the “transportation & communication” category, “maintenance and repair charge of transportation equipment” ($Trans_{2,t}$) and “communication services” ($Trans_{4,t}$) are the leading items of the consumption.

The consumption on “amusement & education” is associated with the discards of several waste fractions as shown in the MSW discard model. In this category, the “education expenses” ($AE_{5,t}$) and the “traveling expenses” ($AE_{1,t}$) are the leading items of the consumption; meanwhile, the consumption on “entertainment expenses” ($AE_{2,t}$) has a large increase over the period. The results appear to reflect the image of an aging society that the adult education will be popularized, and people are more willing to improve their life quality by purchasing more commodities and services in terms of entertainment.

As for the “miscellaneous item” category, the results suggest that the consumption on “other non-saving insurance expenses” ($Mis_{8,t}$) occupies the largest portion and has the biggest increase among the subcategories. This is consistent with the increase on the "health insurance" ($Med_{4,t}$) in the aging society.

As shown in Fig. 5-20, all the projections of the annual per capita consumption expenditure for the three scenarios are increasing due to the assumptions of the scenarios in which the economy continues improving at different speeds over the period. However, in Fig. 5-20 and Fig. 5-21, different settings of the socioeconomic variables lead to different effects on the future trends for the distributions of per capita consumption expenditure among the categories and subcategories based on the consumption preferences of the individuals. Subsequently, such different levels of changes in consumption items as well as the assumed MSW policy variables result in different future trends in the MSW discards by waste fraction.

Using the consumption terms estimated from the previous models and the assumed policy variables, the ex-ante forecasting of MSW discards by waste fraction is performed under the three scenarios. The projections for MSW fractions and overall per capita MSW discards are plotted in Fig. 5-22 and Fig. 5-23, reflecting the possible evolution of MSW discards influenced by the effects of the consumption factor and those of the MSW policy measures.

The MSW discards are assumed to be the trade-off between the effects of the consumption factors and those of the MSW policy measures in the modeling work. Therefore, concrete strategies can be proposed form the perspectives of the two influencing factors. Therefore the discards of MSW fractions are all the highest in the high consumption scenario (Scenario C), mediate in the BAU scenario (Scenario A), and the lowest in the low consumption scenario (Scenario B) since the effects of MSW policy measures are assumed the same for the scenarios.

In Fig. 5-22, the future trends of the MSW discards can be classified into four types.

With the assumed socioeconomic changes and the policy variables in the scenarios, plastic waste, food waste, and moisture content of waste are increasing monotonously, implying that the effect of the consumption factors prevail over that of the policy measures during 2006-2021 while for moisture content of waste, the two factors are

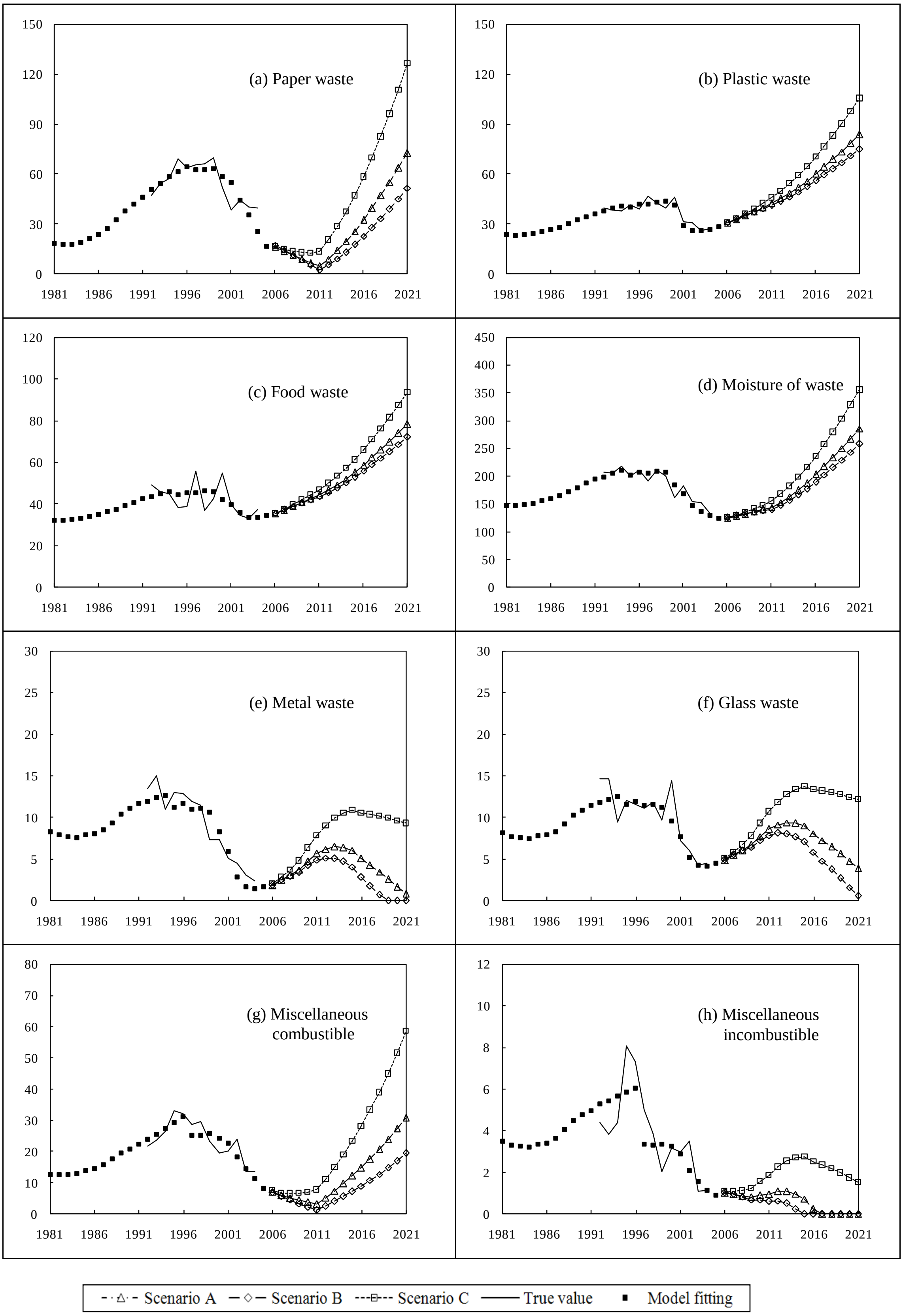

Fig. 5-22 Model fitting and ex-ante forecasting curves of the annual per capita MSW discards by waste fraction. (The horizontal axis denotes time (year); the vertical axis is the annual per capita MSW discards (kg)).

Note: The model fitting denotes the backcasts, the estimates, and the ex-post forecasts during 1981-2005 while the ex-ante forecast period denote the period of 2006-2021.

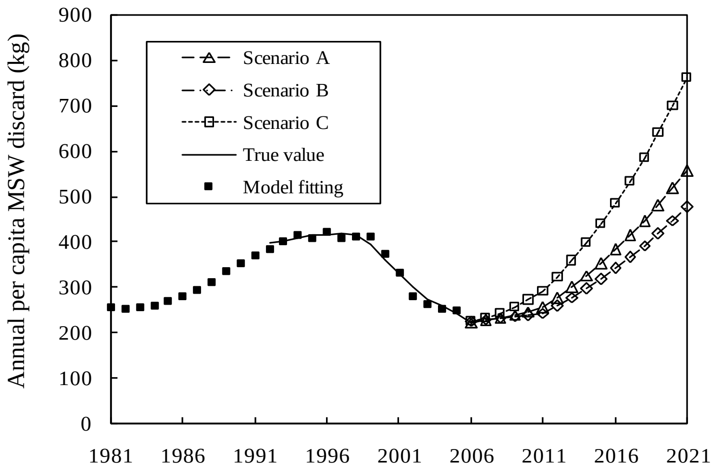

Fig. 5-23 Model fitting and ex-ante forecasting curves of the annual per capita overall MSW discards.

Note: a. The model fitting denotes the backcasts, the estimates, and the ex-post forecasts during 1981-2005 while the ex-ante forecast period denote the period of 2006-2021.

b. The estimates of the model fitting are calculated by the backcasting via the Approach-2 (the sequential estimation via the estimation model system).

initially balanced. Therefore, more enhanced policy measures should be taken for the three waste fractions. Particularly for plastic waste, a decreasing trend appears from 2002 to 2004, which is influenced by the “Restriction on the Use of Plastic Bags” policy (Dum_2), but after that year, the effects of the consumption factors appear to triumph over that of Dum_2. Hence, strict regulations, e.g., the ban on using plastic packages, should be carried out, or alternatively, some green consumption activities on reducing the excess consumption in terms of the plastic waste can be advocated and promoted. Also, for food waste, the effect of the “Mandatory Household Classification and Food Waste Recycling” (Dum_3) may be expected, however, more policy measures are still in need. It should be noted that the ratio of expenditure on “food out from house” to the total food expenditure is significantly getting higher due to the lifestyle changes. Since the food waste in Fig. 5-22 (c) involves the waste from the commercial food sector like restaurant, the significantly increasing consumption on “food out from house” makes restaurants become a potential large discard source of food waste. Some countermeasures can be proposed on such commercial food sector. As for the moisture of waste, its future trend appears to continue dropping because of the significantly prevailing MSW policy effect. Besides, newly strict regulations implemented after 2006, such as the revised “Management Criteria for Public Landfill facilities” and “Recycling of Waste Food Oil” (as shown in Table 5-8) may reduce the moisture content to a higher extent than the model projections though their effeteness are still unknown.

Owing to the rapidly increasing recycling rate, the discards of paper waste and the miscellaneous combustibles are considerably reduced up to 2011 (see Fig. 5-22 (a) and (g)). Since the two series will turn to rapidly increase afterward, more active policy measures in terms of plastic waste are required after 2011. The differences in the two phases are mainly due to the assumed recycling rate. Accordingly, the recycling rate may rise significantly at the beginning of developing the recycling system while it may ascend mildly afterward. Thus, the discards of the two waste fractions are increasing since the influences of the changes of the recycling rate are relatively impaired compared with the increases of the consumption items since 2011.

On the other hand, the ex-ante forecasts of metal waste and glass waste will rise in the near future but subsequently diminish (see Fig. 5-22 (e) and (f)) due to the interaction of the effect of consumption factors and that of the MSW policy measures. Current recycling policy measures for the two materials should be enhanced in near future so as to improve the policy effectiveness on reducing the two waste fractions.

The last type is the behavior of the miscellaneous of incombustibles. Seeing Fig. 5-22 (h), the ex-ante forecasts are slumped except for slight increasing during several years. Thus, the current MSW policy measures seem to work well on reducing this waste fraction.

Up to the present, TEPA has made lots of efforts on establishing a public recycling system. However, next national MSW plan should focus on promoting new policy measures associated with “reduce” and “reuse” of the “3R” principle if the consumption continues to increase. For example, to improve the citizen’s environmental consciousness by means of comprehensive social education activities, to propose policy measures with economic incentives for the “green-buy” activities, or to impose environmental taxes on the commodities which may result in high environmental loads. Since the majority of developing countries set the policy goal in a higher priority for their economic development, which may results in increasing consumption, a more sustainable consumption pattern with little environmental loads is crucial at the process of economic development.

On the other hand, the effectiveness of the current MSW policy measures should be continually improved by raising the administrative budget of MSW policy measures, increasing the manpower of the civil servants who are in charge of MSW affairs, or promoting regional cooperation for the MSW collection, treatment, and recycling system. Meanwhile, more standard landfill sites for the fly ash and bottom ash from the incinerators should be established since the incineration would be the main intermediate process technology. Besides, from Fig. 5-22 (d), the heat value of the MSW is expected to be increasing since the moisture of waste are on a lower level until 2011. Hence, two ways of resource recovery should be considered and enhanced for the incineration in the near future: reproducing the MSW into the refuse derived fuel (RDF) and recovering energy from the incineration process.

In addition, since the higher recycling rate in the future would be expected, more recyclable waste will be collected. Thus an economically efficient market for the recycling materials and a cost-efficient reproduction industry, which uses the recycled resources as the raw materials in the production process, are required. The “economic instrument” type of policy measures, such as subsidy and tax exemption, would be efficient in developing the recycling market and reproduction industry.

5.5 Application of the Estimation Model System

Not only to manage the quantity and composition of MSW discards, this section makes an attempt but also to apply the modeling into two issues in terms of the MSW management system. As for future application, the estimation of MSW discards is of particular importance for rational planning and designing MSW management system, such as the capacity planning of intermediate treatment and disposal system and the estimation of potential environmental loads from MSW management system. The ex-ante forecasts of the MSW discards produced in the previous section are used in support of the application on the two issues.

5.5.1 Estimation of the Required Capacity of the MSW Treatment and Disposal System

As discussed in Chapter 4.1, three main procedures are proposed for the projection of required treatment capacity and are applied in this section.

In Taiwan, the municipalities take the responsibility for the collection, treatment, and disposal of MSW. After the generation of MSW, one portion is recycled, which is reflected by the recycling rate of overall fractions (including the recycling of waste of potential resources, food waste, and bulky waste). The rest part is the MSW discards defined in this study (or called MSW clearance in Taiwan). Afterward, the MSW discards are directly processed by the landfilling, the incineration, the dumping, and the miscellaneous. Such flow of treatment and disposal of MSW discards in Taiwan can be represented by Fig. 5-24. However, examining the current statistics in Taiwan, the database does not reflect the portion of the distribution of ashes generated from the incineration process, and such part is of particular importance since the incineration is increasingly popularized. Moreover, during 2003-2007, average 14% of the amounts of incinerated MSW discards are the ashes, and such portion has to be final disposed in the landfill sites (TEPA, 2008e).

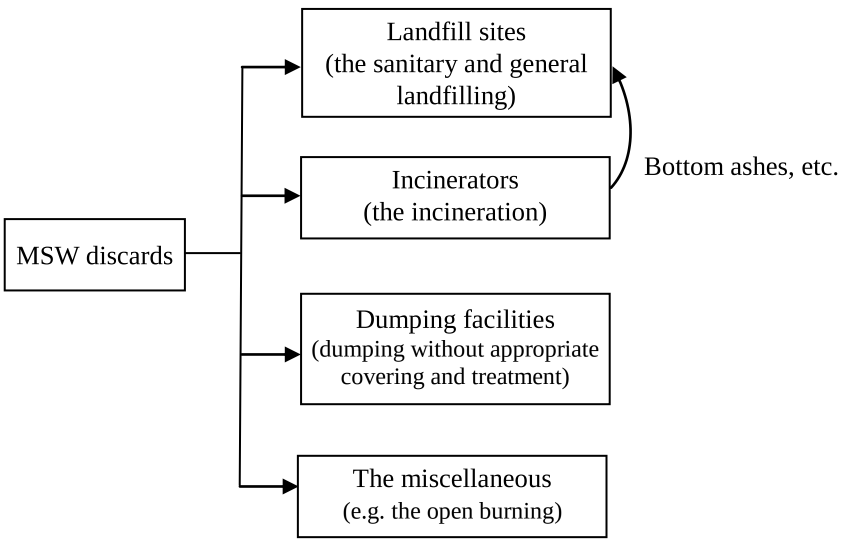

Fig. 5-24 The flow of the treatment and disposal of MSW discards in Taiwan.

Firstly, the ex-ante forecasts of the annual overall per capita MSW discards obtained in the previous section are used in the estimation of the required capacity of MSW treatment and disposal system.

Secondly, the distribution of the MSW discards is to be confirmed. As shown in Fig. 5-6, the current technological options for treating the MSW discards mainly comprises the incineration and the landfilling (including sanitary landfilling, general landfilling, and open dumping). In particular, the incineration rate of MSW discards, $Inci_t$, has achieved over 80% since 2006. The TEPA has started to establish a detailed database to collect the important technical indicators in terms of the operation of the incinerators since 2003 (TEPA, 2008d). Moreover, the TEPA made a comprehensive survey for the existing landfill sites in 2007 (TEPA, 2008e). Based on the two databases as well as the regular environmental statistics, the flow of the treatment and disposal of MSW discards in Taiwan, as represented in Fig. 5-24, can be conducted.

Thirdly, the information for the design capacity and throughput of the MSW treatment and disposal facilities are collected as shown in Table 5-6. However, the data of the design capacity for the landfill sites is not available in the current database in Taiwan so that the estimation of the remaining spaces of the landfill sites as well as further considerations for the capacity planning of the landfilling cannot be achieved.

Subsequently, as discussed in Chapter 5.3, the incineration has been chosen as the main technology for MSW treatment in Taiwan due to the limited land resources. Such technological option will not be changed unless a more feasible one in terms of the cost and the technology concern. Hence, the landfill sites are responsible for the bottom ashes from the incineration and from the direct disposal of MSW discards owing to the spatial inequality of the incinerators.

The estimation during 1992-2005 is based on the actual data along with the estimates generated from the estimation model system, and the ex-ante forecasting is according to the assumed scenarios for the socioeconomic changes and the policy prospects during 2006-2021. Thus, based on the projected quantity of MSW discards and the information of its flow in the treatment and disposal system, the demand of the required capacity of MSW treatment and disposal system can be estimated.

Fig. 5-25 (a) and Fig. 5-25 (b) depict the future trend of the demanded treatment capacity of MSW treatment and disposal system for the landfilling and the incineration, respectively. The modeling is conducted from 1992 to 2021 using the true values along with the estimates (1992-2004), the ex-post forecasts (2005), and the ex-ante forecasts (2006-2021) of the overall MSW discards. With the support of the current treatment capacity of MSW under operation in Taiwan, as shown in Table 5-6, concrete policy proposals for the management of MSW treatment and disposal can be made.

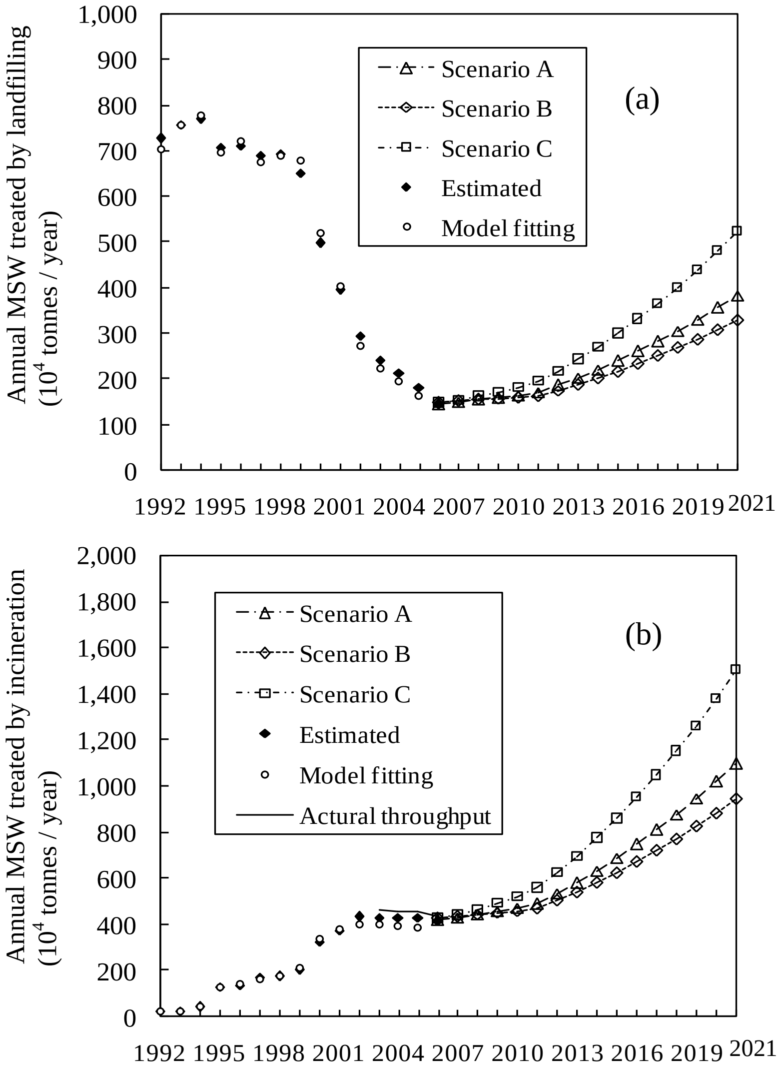

Fig. 5-25 Estimation and future projection of the required capacity of the MSW treatment and disposal facilities: (a) the landfill sites and (b) the incinerators.

Note: The “estimated” denotes the estimated required capacity by using the true values of the MSW discards; **t**he model fitting denotes the estimation of the required capacity using the estimates, and the ex-post forecasts of the estimation model system of MSW discards during 1992-2005 while the ex-ante forecasts of the estimation model system are used during 2006-2021.

Since the actual throughput is not available for the landfilling, Fig. 5-25 (a) provides the preliminary image for the period from 1992 to 2005. Comparing to Fig. 5-25 (a) and Table 5-6, the disposal capacity level of the landfill sites in 2006 (86.4 10^4 tonnes/yr) is always lower than the required capacity before 2012 under the scenario analysis (even considering the most pliable saturation, the low consumption Scenario B). One reason may be the deficiency of the consideration of the rapidly increasing ashes from incineration. Even many incinerators are set up, the required capacity of the landfilling is still not sufficient. Thus, the decision-makers should progressively enlarger the level of the disposal capacity for both MSW and the incineration ashes. Also, more efficient policy measures on reducing the amount of MSW discards can be considered and carried out so as to eliminate the pressure of the construction of new landfill sites since the new construction of landfill sites or incinerators is usually under strong opposition by the citizens, as the well-known “NIMBY” (not in my backyard) phenomenon. Indeed, in the end of 2006, the TEPA started to promote a new order, regulating combustible MSW not be dumped in the landfill sites until it is incinerated. Therefore, it would be expected that the required landfilling treatment capacity would be at a low level since the landfill sites would primarily response for the ashes afterward. However, the incineration ashes will occupy a higher proportion. Actually, as the incineration is increasingly popularized, the landfilled materials vary rapidly. Fig. 5-26 further shows the modeled composition of the landfilled materials during 1992-2005, indicating that the incineration ashes occupy a large portion in the landfill sites. Thus, sophisticated covering operation procedures should be adopted at existing landfill sites for stabilizing the dumped ashes, and specific landfill sites for ashes should be further established soon.

On the other hand, in Fig. 5-25 (b) shows the ex-ante forecasting of the demanded incineration capacity for MSW. Apparently, the current level of incineration capacity (the design capacity, 767.3 10^4 tonnes/yr), as shown in Table 5-6, is significantly larger than the actual throughput of the treated MSW. Hence, new incinerators are not essential in the near future, and the existing incinerators have the remaining capacity to treat some general industrial waste to maintain their optimal operation condition.

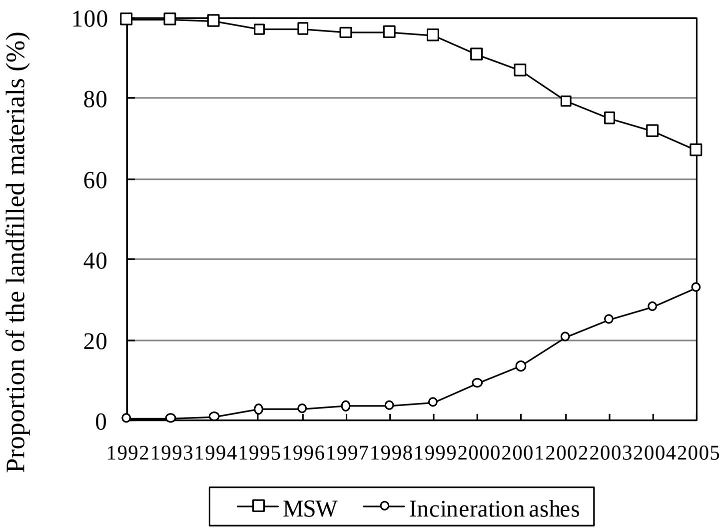

Fig. 5-26 The modeled composition structure of the landfilled materials during 1992-2005.

However, cross-prefecture MSW treatment network should be established to improve the incineration. In addition, sophisticated covering operation procedures should be adopted at existing landfill sites for stabilizing the dumped ashes in support of the incineration. Besides, in Fig. 5-25 (b), the modeled MSW throughput of the incineration is lower than the available data during 2003-2007, reflecting the fact that the incinerators help treat the stocked MSW, which were generated in the earlier times.

Furthermore, considering the most crucial condition (the Scenario C), the demanded incineration capacity are larger than the current service level from 2015. More incinerators have to be constructed in the earlier 2010s if no more additional efficient policy measures on reducing the amount of MSW discards are implemented.

By using the estimation model system of MSW discard, the required capacity of MSW treatment and disposal system can be forecasted up to 2021 in light of the socioeconomic changes and the policy effects. Possible ranges of the remaining capacity of MSW treatment and disposal system are projected based on the assumed scenarios. The analysis results show that the municipalities should promote the current level of disposal capacity of the landfill system for the potential large amount of incineration ashes. In order to reduce the amount of disposed ashes, the reuse of the incineration ashes should be further promoted. Besides, new incinerators are not crucially needed up to 2013, however, are required after 2014. Thus, some incinerators can support the treatment of the industrial waste.

To sum up, the established estimation model system of MSW discards can serve as a useful decision support tool for the management of MSW treatment and disposal system. It can provide reliable future projections of the required capacity of MSW treatment and disposal system. Such information is of particular importance for the policy decision-makers.

5.5.2 Estimation of the GHG Emission from the MSW Treatment and Disposal System

Taiwan made a successful economic development in the last decades. However, as previously discussed, such development resulted in the large amount of MSW discards, and subsequently, the large amount of the GHG was emitted in the treatment and disposal of MSW. Meanwhile, Taiwan is one of the dangerous insular zones threatened by the increasing height of the sea-level due to the global warming. As a developing economy, Taiwan has the obligation to reduce its GHG emission although it is excluded of the “Kyoto Protocol”. In 2004, the GHG emission of Taiwan ranked approximately 21^{th} on GHG emission all over the world, and even the annual per capita overall GHG emission reached approximately 11.26 tonnes CO_2 eq., ranking 18^{th} worldwide (IEA, 2006). As one member of the world communities, Taiwan has to reduce its GHG emission rate imminently. Thus, it is imperative to estimate the GHG emission from the MSW treatment and disposal system and find its elimination strategies.

On the MSW treatment system in Taiwan, firstly the landfilling was comprehensively adopted. However, since the land resources in Taiwan are pretty limited, TEPA turned the priority of treatment options to incineration after the 1980’s. The distribution structure of MSW intermediate treatment and disposal system is exhibited previously in Fig. 5-6.

Noticeably, it is inevitable to choose incineration as the main treatment technology due to the limited land resources in Taiwan. But inefficient pre-classification of MSW for the incinerators will affect the stability of incineration and even result in the emission of hazardous air pollutants such as dioxin and polycyclic aromatic hydrocarbons (PAHs). Thus, TEPA claimed to promote a “zero waste discard” society (TEPA, 2008a) so that not only resources can be used more efficiently but also relevant air pollution problems can be eliminated. Up to the present more and more recycling projects are implemented, thus it is expectable that the MSW discard and GHG emission during MSW treatment processes can be reduced.

5.5.2.1 Estimation the GHG emission from the Treatment and Disposal of MSW during 1992-2004

Using the equations discussed in Chap 4.2, GHG emission from landfill and incineration for MSW treatment can be estimated. Emission coefficients used in the calculation are from IPCC 2006 guideline (IPCC, 2006), and a domestic study in Taiwan (Yang et al., 2004).

5.5.2.1.1GHG Emission from Landfill Disposal of MSW

In the estimation of the methane emission from landfill, firstly, the methane emission from each waste fraction is estimated by FOD model using Eq. (4-2) to Eq. (4-5). Subsequently the amount of methane emission of each waste fraction is adding up to obtain the net methane emission with Eq. (4-1). Since the MSW composition data was recorded on a dry basis before 2004, the dry-basis coefficients are used in the estimation. The estimation period is from 1992 to 2004 due to the availability of required data. MCF_t value is set as 1 for sanitary landfill, 0.6 for general landfill site, and the weighted average value is calculated for the estimation (Yang et al., 2004); methane recovery is not considered since the equipment for methane recovery is not popular in the landfill sites; the recommended value of OX_t from IPCC is zero; F is assumed as 0.5, the default value in the IPCC’s guideline. Annual amount of MSW discards treated by landfilling and detailed parameters are described in Table 5-26.

In the FOD model, an important coefficient is the reaction constant (κ) in the FOD model, associated with the decaying behavior of waste. This value is affected by the moisture conditions, the degradability of waste, the circumstances disposal sites, etc, rationally ranging from 0.2 for a rapidly degradable material in a warm and wet region to 0.02 for a slowly decomposable waste in a frigid and dry region.

Table 5-26 Annual amounts of MSW discard treated by landfilling and typical values of parameters for waste fractions: 1992-2004.

year	$WEL_{i,t}$ (Gg /yr) (on a dry basis)					DOC_t (Gg-C/Gg- waste)					MCF_t (fraction)	DOC_f (fraction)	κ (yr^{-1})		(1-R_t)	F (fraction)
	Paper	Food	Textile	Leather	Garden	Paper	Food	Textile	Leather	Garden			Food	Others		
1992	864.04	894.28	137.98	60.13	175.87	0.44	0.38	0.30	0.47	0.49	0.881	0.77	0.20	0.13	1	0.5
1993	1027.37	866.11	189.31	57.20	213.67	0.44	0.38	0.30	0.47	0.49	0.870	0.77	0.20	0.13	1	0.5
1994	1070.72	839.29	171.79	28.57	167.50	0.44	0.38	0.30	0.47	0.49	0.892	0.77	0.20	0.13	1	0.5
1995	1151.21	641.99	222.23	31.49	208.27	0.44	0.38	0.30	0.47	0.49	0.853	0.77	0.20	0.13	1	0.5
1996	1057.18	647.97	172.50	36.89	201.19	0.44	0.38	0.30	0.47	0.49	0.879	0.77	0.20	0.13	1	0.5
1997	1048.01	895.82	208.67	40.65	174.85	0.44	0.38	0.30	0.47	0.49	0.908	0.77	0.20	0.13	1	0.5
1998	1072.42	598.55	172.46	27.16	157.41	0.44	0.38	0.30	0.47	0.49	0.935	0.77	0.20	0.13	1	0.5
1999	1098.12	669.05	159.37	18.39	149.87	0.44	0.38	0.30	0.47	0.49	0.945	0.77	0.20	0.13	1	0.5
2000	655.20	689.74	150.57	33.54	83.48	0.44	0.38	0.30	0.47	0.49	0.938	0.77	0.20	0.13	1	0.5
2001	402.53	414.20	72.93	7.28	61.55	0.44	0.38	0.30	0.47	0.49	0.949	0.77	0.20	0.13	1	0.5
2002	342.53	266.40	41.66	6.85	50.56	0.44	0.38	0.30	0.47	0.49	0.962	0.77	0.20	0.13	1	0.5
2003	264.94	218.49	30.38	1.77	31.18	0.44	0.38	0.30	0.47	0.49	0.975	0.77	0.20	0.13	1	0.5
2004	236.89	223.38	36.78	6.53	36.85	0.44	0.38	0.30	0.47	0.49	0.983	0.77	0.20	0.13	1	0.5

Note: a. Conservatively no methane recovery is assumed in the process, that is, R_t is set to zero.

b. The rational ranges of the DOC_t are (0.44 – 0.50) for paper waste, (0.20 – 0.50) for food waste, (0.25 – 0.50) for textile waste, 0.67 for leather waste, and (0.45 – 0.55) for garden trimmings, respectively.

c. MCF_t is set referring to Yang et al. (2004); κ is assumed as 0.2 for food waste, otherwise, 0.13; F is assumed as 0.5 based on IPCC's guideline.

Fig. 5-27 demonstrates the decomposition behavior of unit weight of deposited decomposable organic matters (as discussed in Eq. (4-4) and Eq. (4-5), deciding the amount of methane emission) under different values of κ, and Table 5-27 provides its half-life time and duration required to decay 99% of weight under different value κ. From Fig. 5-27 and Table 5-27, the decomposition behavior of the FOD model would be quite clear, and the results show that the decaying processes are quite different with different κ values. Thus, there is a large uncertainty in deciding the κ value in the estimation. Comparing the triangular method and the FOD model with different κ values, the two approaches would have a similar methane release behavior when κ is approximately 0.13, in which the half-life time of waste are around 6 years after deposition. Since the triangular method is designed on the basis of a tropical Indian case (Kumar et al., 2004), the value of κ for most waste fractions is assumed as 0.13 in Taiwan, where is of a wet and subtropical climate, except for food waste, set as the most rapid rate, 0.2. Meanwhile, it should be noted that the FOD model will generate underestimates for the first several years during the estimation period since the GHG emission resulted from the past deposited MSW, which is not available, cannot be accounted in the estimation.

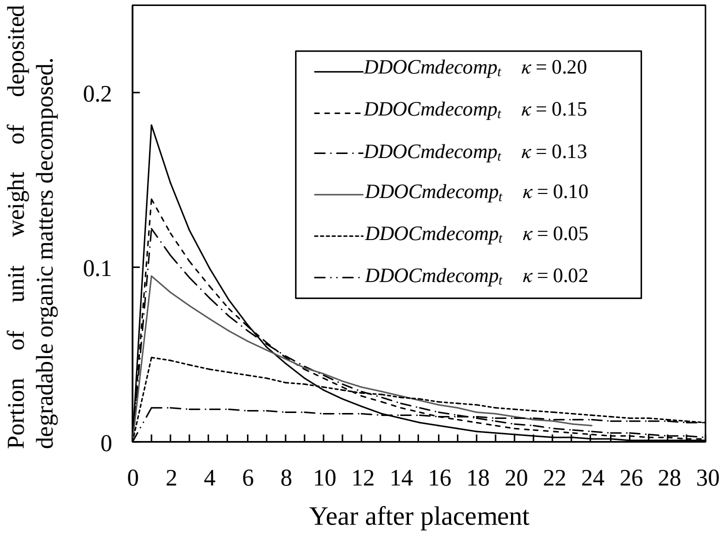

Fig. 5-27 Portion of unit weight of deposited degradable organic matters decomposed.

Table 5-27 Decaying time of unit weight of deposited decomposable organic matters with different values of reaction constant. *Unit: year (after deposition)

	Reaction constant (κ) (yr^{-1})				
	0.2	0.15	0.13	0.1	0.05
Half-life time *	4	5	6	7	14
Duration required to decay 99% of unit weight of waste*	24	31	36	46	92

Table 5-28 reports the estimation results. In Table 5-28, the annual net methane emission is decreasing with the rapidly decreasing MSW treated by landfilling after 2000 due to the increasing tendency of the use of incinerators. The estimates in the first year in the estimation period would be zero because the FOD model accounts for the accumulated deposited organic decomposable matters as Eq. (4-4) shows. The portion of organic matters in MSW is still likely to decline since higher incineration rate of MSW is proposed by national policy in Taiwan and food waste is separated from MSW discard as potential resource (TEPA, 2008a). Thus, a lower net methane emission from the landfilling of MSW may be expected.

Table 5-28 Methane emission from MSW landfill disposal: 1992-2004.

year	$LMEE_{i,t}$ (Gg CH_4/yr)						$LMEE_{i,t}$ (Gg CO_2 eq. /yr)					
	Total	Paper	Food	Textile	Leather	Garden	Total	Paper	Food	Textile	Leather	Garden
1992	0	0	0	0	0	0	0	0	0	0	0	0
1993	57.423	20.965	27.865	2.283	1.558	4.752	1320.731	482.188	640.900	52.502	35.843	109.297
1994	110.282	43.021	49.460	5.097	2.832	9.873	2536.496	989.482	1137.573	117.221	65.139	227.081
1995	154.888	64.078	66.970	7.352	3.237	13.252	3562.419	1473.785	1540.303	169.105	74.441	304.785
1996	188.222	83.301	74.191	10.014	3.632	17.083	4329.101	1915.928	1706.401	230.330	83.535	392.907
1997	215.825	98.735	80.884	11.640	4.143	20.423	4963.983	2270.900	1860.329	267.726	95.289	469.739
1998	249.174	112.894	94.978	13.777	4.723	22.801	5730.996	2596.567	2184.490	316.881	108.638	524.419
1999	268.837	126.737	97.547	15.125	4.894	24.534	6183.247	2914.946	2243.587	347.869	112.572	564.272
2000	288.878	139.857	102.219	16.108	4.809	25.885	6644.187	3216.710	2351.032	370.485	110.603	595.357
2001	293.385	139.735	106.574	16.797	5.148	25.132	6747.863	3213.908	2451.196	386.323	118.411	578.025
2002	279.018	133.224	101.161	16.049	4.724	23.860	6417.414	3064.153	2326.707	369.126	108.650	548.779
2003	259.564	126.053	91.882	14.845	4.342	22.442	5969.972	2899.220	2113.293	341.426	99.860	516.172
2004	238.652	117.800	82.760	13.591	3.863	20.639	5489.006	2709.390	1903.481	312.593	88.853	474.689

Note: The estimates in 1992 are zero due to the missing data in the earlier times.

Moreover, Fig. 5-28 plots the time series trends of the estimates of methane emission (CO_2 eq.) by waste fraction and their shares. The results indicate that paper waste and food waste are responsible for more than 80 % of the net GHG emission from the landfilling of MSW. More intensive reduction measures on the recycling and reuse of paper waste and food waste should be implemented at the perspective of reducing the GHG emission. However, the reuse of food waste, e.g. composting, may become another potential emission source of methane or other GHG in Taiwan, and this part will be discussed later.

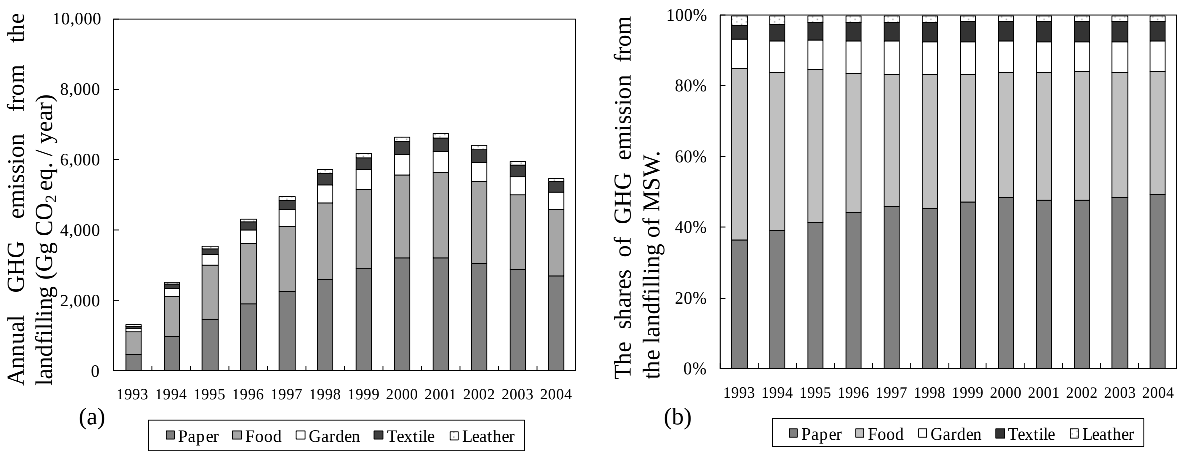

Fig. 5-28 Time series trends of GHG emission (CO_2 eq.) from the landfilling of MSW by waste fraction: (a) the amount; (b) the shares.

5.5.2.1.2 GHG Emission from Incineration of MSW

As for the estimation of the GHG emission from the incineration process, Table 5-29 collects the typical value of parameters referring to IPCC report (IPCC, 2006) for performing the estimation from Eq. (4-6) to Eq. (4-8). Because MSW discard in terms of waste composition is required in this part, the true data from 1992 to 2004 are used in the estimation. Table 5-30 shows the results of CO_2, methane, and N_2O emission from incineration process of MSW. In Table 5-30, it is obvious that direct CO_2 emission occupies much more shares than mathane and N_2O emission in the incineration of MSW. Furthermore, plastic waste contributes more than 90% of the CO_2 emission from the incineration of MSW than other categories (see Fig. 5-29). Redunction on GHG emission in incineration can be achieved if plastic waste is eliminated through the "3R" principles, e.g. reducing excess consumption on such commodiites as well as reusing and recycling them during the economic avtivities. However, the food waste does not contribute GHG emission in incineration since the fossil carbon fraction (*FCF*) of food waste is not available in the current references.

Table 5-29 Typical values of parameters recommended by IPCC in the estimation for incineration process of MSW (IPCC, 2006).

Parameter		Value	Parameter		Value
CF_i	Paper	0.46 (0.42-0.50)	FCF_i	Paper	0.01 (0-0.05)
	Plastics	0.75 (0.67-0.85)		Plastics	1 (0.95-1)
	Food	0.38* (0.20-0.50)		Food	--
	Textile	0.50 (0.25-0.50)		Textile	0.2 (0-0.50)
	Leather	0.67 (0.67)		Leather	0.2 (0.2)
	Garden	0.49 (0.45-0.55)		Garden	0
EFM		0.2	*EFN*		47

Note: a. *: recommended value from Yang et al., 2004 and is the same as the default value of IPCC 2006 guideline.

b. Values in the parentheses represent the rational ranges of the parameter.

c. *EFM* and *EFN* use the value for the stocker-type incinerator.

Table 5-30 GHG emission from MSW incineration process: 1992-2004.

Year	Total GHG emission (Gg CO_2 eq./yr)	$ICO_2E_{s,t}$ Total (Gg CO_2/yr)	Paper (Gg CO_2/yr)	Plastics (Gg CO_2/yr)	Textile (Gg CO_2/yr)	Leather (Gg CO_2/yr)	$IMME_t$ (Gg CH_4/yr)	(Gg CO_2 eq. /yr)	$IMNO_2E_t$ (Gg N_2O/yr)	(Gg CO_2 eq. /yr)
1992	71.463	67.909	0.514	64.566	1.043	1.786	0.00005	0.0012	0.012	3.553
1993	67.655	64.189	0.572	60.365	0.937	2.315	0.00005	0.0011	0.012	3.465
1994	111.341	105.600	0.976	100.342	0.780	3.501	0.00008	0.0019	0.019	5.739
1995	380.095	361.989	3.664	339.240	3.046	16.040	0.00026	0.0060	0.061	18.100
1996	369.958	350.967	3.520	330.639	3.744	13.064	0.00027	0.0063	0.064	18.985
1997	545.875	522.333	4.493	492.123	5.324	20.393	0.00034	0.0078	0.080	23.534
1998	527.853	503.623	4.710	477.898	3.662	17.353	0.00035	0.0080	0.082	24.222
1999	610.207	582.086	6.027	553.888	2.969	19.203	0.00040	0.0093	0.095	28.111
2000	1239.064	1194.117	7.901	1137.235	11.260	37.721	0.00065	0.0149	0.152	44.932
2001	1125.157	1073.152	7.397	1036.343	3.469	25.943	0.00075	0.0172	0.176	51.988
2002	1424.520	1364.455	10.658	1324.245	5.335	24.218	0.00086	0.0199	0.203	60.045
2003	1435.931	1376.026	10.607	1341.870	1.704	21.845	0.00086	0.0198	0.202	59.885
2004	1640.397	1580.448	11.192	1530.140	7.518	31.598	0.00086	0.0198	0.202	59.929

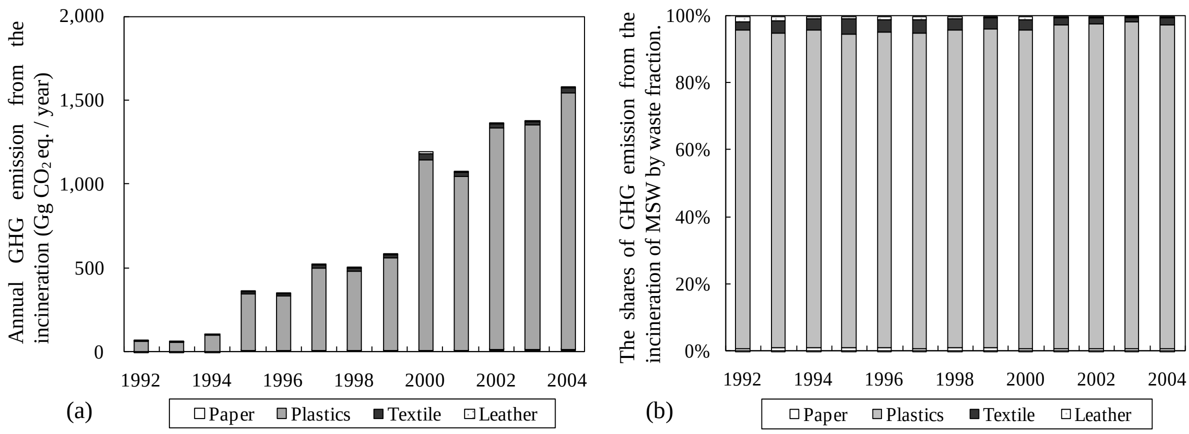

Fig. 5-29 Time series trends of GHG emission (CO_2 eq.) from incineration of MSW by waste fraction: (a) the amounts; (b) the shares.

5.5.2.1.3 GHG Emission from the Composting of the Recycled Food Waste

Using Eq. (4-9) and Eq. (4-10) with IPCC's default emission coefficients, methane and N_2O emission from the composting of the recycled food waste in Taiwan can be estimated as reported in Table 5-31. Since the amount of recycled food waste for composting is not large, such GHG emission is much less than that contributed by incineration and landfilling. However, such calculation is important in a life-cycle perspective.

Table 5-31 GHG emission from recycled food waste treated by composting: 1992-2004.

Year	$M_{i,t}$ (Gg/yr)	$EF_{composting}$* (for CH_4)	(for N_2O)	$BMEE_t$ (Gg CH_4/yr)	(Gg CO_2 eq. /yr)	BN_2OE_t (Gg N_2O/yr)	(Gg CO_2 eq. /yr)	Total GHG emission (Gg CO_2 eq. /yr)
1992	7.855	4	0.3	0.031	0.723	0.002	0.698	1.420
1993	--	4	0.3	--	--	--	--	--
1994	1.370	4	0.3	0.005	0.126	0.0004	0.122	0.248
1995	6.286	4	0.3	0.025	0.578	0.002	0.558	1.137
1996	2.520	4	0.3	0.010	0.232	0.001	0.224	0.456
1997	14.173	4	0.3	0.057	1.304	0.004	1.259	2.562
1998	0.528	4	0.3	0.002	0.049	0.000	0.047	0.095
1999	19.493	4	0.3	0.078	1.793	0.006	1.731	3.524
2000	2.782	4	0.3	0.011	0.256	0.001	0.247	0.503
2001	0.216	4	0.3	0.001	0.020	0.000	0.019	0.039
2002	3.706	4	0.3	0.015	0.341	0.001	0.329	0.670
2003	22.290	4	0.3	0.089	2.051	0.007	1.979	4.030
2004	66.562	4	0.3	0.266	6.124	0.020	5.911	12.034

Note: a. $M_{i,t}$ denotes the amount of recycled food waste treated by composting.

b. Conservatively, no methane recovery is assumed in the process, i.e., R_t is set to zero.

c. * denotes the typical values of parameters recommended by IPCC 2006 guideline. The rational ranges of $EF_{composting}$ for methane and N_2O are (0.03 – 8) and (0.06 – 0.6), respectively, on a wet weight basis.

d. The data in 1993 is missing in official records.

As a consequent, Fig. 5-30 demonstrates the annual CO_2 eq. emission from the main divisions of the MSW processing system in Taiwan. As the decreasing of MSW emission due to the intensive recycling measures by the government, both CO_2 eq. emissions from incineration and landfilling are decreasing. Moreover, per weight MSW treated by incineration produces less CO_2 eq. emission than that treated by landfilling. Besides, comparing the estimation results and national statistics (TEPA, 2008b), the GHG emission from MSW treatment and disposal system is 7,842.6 Gg CO_2 equivalence in 2002 in Taiwan, approximately 2.86 % of Taiwanese total CO_2 eq. emission, although the original national GHG emission inventory was prepared by a different methodology, in which GHG emission from MSW treatment and disposal system was not included.

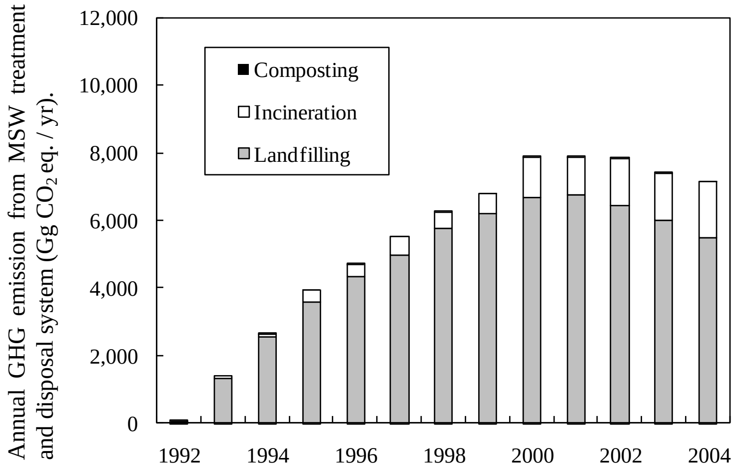

Fig. 5-30 Estimates of annual GHG emission (CO_2 eq.) from MSW treatment and disposal system.

5.5.2.1.4 Interpretation of results

On the evaluation of how "green" or "environmental-friendly" a technology is, from the perspective of the prevention of global warming, Fig. 5-31 presents the comparison between the unit GHG emission rates (the values of the annual GHG emission divided by the weight of MSW treated in the current year, kg CO_2 eq. / kg MSW treated) by landfilling, incineration, and composting, respectively. The value for the lanfilling is zero in the first calculation year due to the assumption of the FOD mechanism.

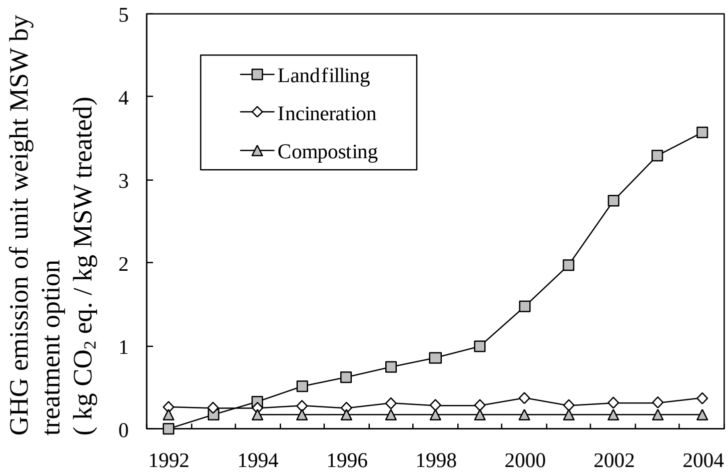

Fig. 5-31 Estimates of the unit GHG emission rate for landfilling, incineration, and composting.

Obviously, the unit GHG emission rate for landfilling is larger than that for that of incineration and composting. One reason is that methane, the main greenhouse gas released in the landfilling, has a 23 times global warming potential larger than that of CO_2, so that the GHG emission from landfilling is enhanced. In addition, the methane emission is estimated on the basis of the FOD model, so that high unit GHG emission rate will be highlighted in the later periods. Besides, the annual amount of MSW treated directly by landfilling is decreasing to a great extent, enlarging the unit GHG emission rate for landfilling since methane released accounts for the deposited amount of MSW. In addition, the composting has the lowest unit GHG emission rate among the three technology options, 0.181 kg CO_2 eq. / kg MSW treated. But since the range of the emission factor for composting is quite large (as described in Table 5-31), more reliable domestic parameters should be developed in the estimation while recommended values are used in this study.

Turning to another viewpoint of Fig. 5-31, the maximum unit GHG emission rates for landfilling and incineration are 3.569 (in 2004) and 0.370 (in 2000), respectively; the minimum unit GHG emission rates for landfilling and incineration are 0 (in 1992) and 0.256 (in 1994), respectively. The minimum of unit GHG emission rates for landfilling is zero due to the missing data problem in previous period. Wholly, these values for landfilling are still much larger than that for incineration. Although such difference is due to the differences of their global warming potential, annual waste composition, as well as the varying amount of deposited organic matters (for landfilling). On the other hand, the unit GHG emission rate for composting keeps constant because only one waste fraction, recycled food waste, is considered in the estimation. The abovementioned results indicate that the composting and incineration are cleaner technology options from the perspective of preventing global warming. However, more detailed data for MSW composition and characteristics in Taiwan is requireded to conduct the estimation procedure provided by IPCC 2006 methodology, e. g. the methane correct factor (*MCF*), as well as the moisture content, total carbon content ration (*CF*), the reaction constant in the FOD model (κ), and fossil carbon content ratio (*FCF*) for MSW fractions. Besides, many emission coefficients in the references use the typical values offered by the IPCC guideline, in fact, the database of domestic parameters should be established for each countries.

5.5.2.2 Ex-ante Forecasting of the GHG Emission from the Treatment and Disposal of MSW during 2005-2021

In this section, the ex-ante forecasts of the MSW discards obtained under the three assumed scenarios in Chapter 5.4.3 are used in the ex-ante forecasting of the GHG emission from the treatment and disposal of MSW during 2005-2021 since the dry-basis composition data is not available.

In the ex-ante forecasting, the waste composition data in 2004 along with the official population projections are used for the required parameters, and the distribution of the options of direct treatment and disposal of MSW uses the actual data up to 2006.

Following the estimation procedures mentioned in Chapter 4.2, the ex-ante forecasts of the GHG emission from the landfilling, incineration, and composting of MSW discards can be obtained, respectively. Fig. 5-32 demonstrates the projected GHG emission by waste fraction from the landfilling process with regards to the three scenarios reflecting the socioeconomic and lifestyle changes. As the ratio of the landfilling decreases in the direct MSW treatment and disposal down to less than 20%, the GHG emission from the landfillingis is slumped to a low level in the three scenarios. Reasonably, among the scenarios the GHG emission is the highest in Scenario C, in which the largest amount of MSW discards for all the waste fractions is generated, and the lowest in Scenario B, in which the smallest amount of MSW discard is produced. Still, paper waste and food waste occupy the largest portion in the GHG emission in the three scenarios due to the varying waste amount and the emission properties.

Subsequently, Fig. 5-33 illustrates the projected GHG emission by waste fraction from the incineration process. The plastic waste is to occupy more than 90% of the GHG emission from the incineration of MSW in the three scenarios. Furthermore, the overall amount of GHG emission from the incineration increases gradually due to the high incineration rate of MSW.

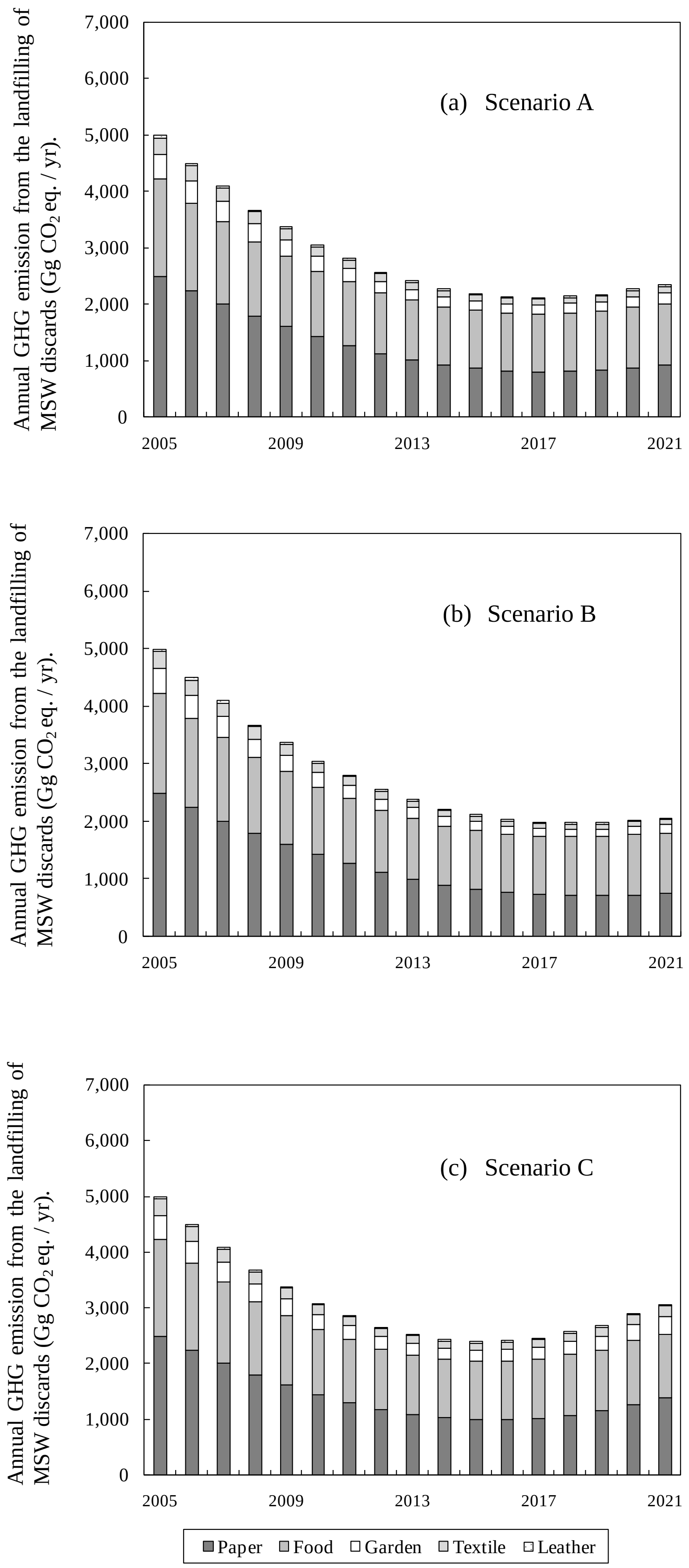

Fig. 5-32 Ex-ante forecasting of the GHG emission from the landfilling of MSW discards in terms of MSW fractions.

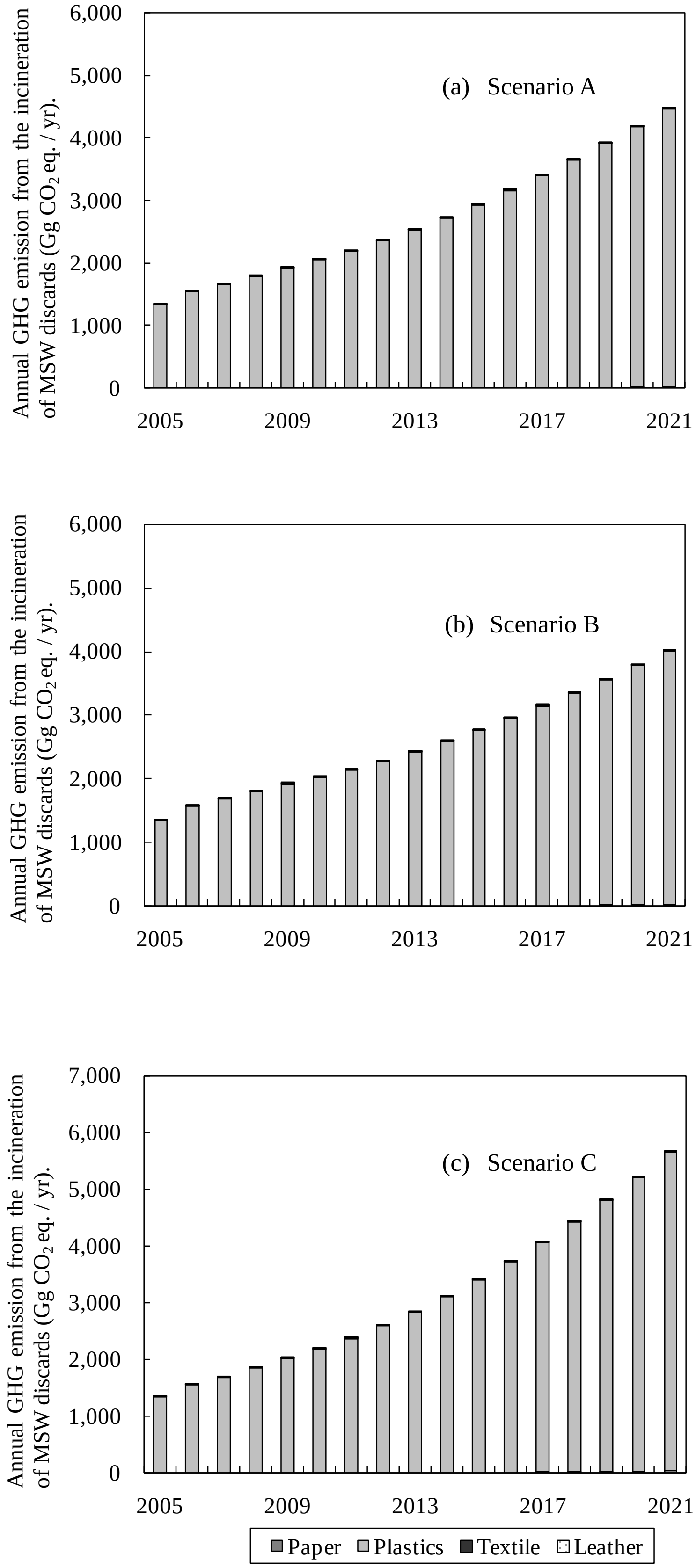

Fig. 5-33 Ex-ante forecasting of the GHG emission from the incineration of MSW discards in terms of MSW fractions.

Fig. 5-34 shows the projected GHG emission by waste fraction from the composting process with the assumed annually 6% increasing rate of the recycled food waste for composting while the projection of the GHG emission is the same in the three scenarios. Indeed, the projection of the GHG emission for the composting of recycled food waste is highly uncertain since the amount of recycled food waste is highly influenced by the policy measures and difficult to be precisely forecasted.

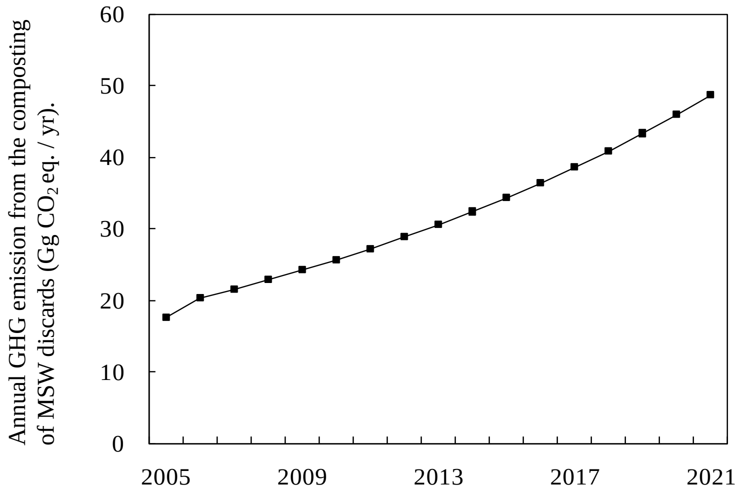

Fig. 5-34 Ex-ante forecasting of the GHG emission from the composting of MSW discards in terms of MSW fractions.

Consequently, Fig. 5-35 demonstrates the modeling results in terms of the options of the treatment and disposal facilities of MSW. Obviously, the amount of GHG emission from the incineration increases gradually due to the high incineration rate of MSW, and it occupies the largest portion among the three technological options although the incineration has a much lower unit GHG emission rate than that of the landfilling as shown in Fig. 5-31.

Furthermore, Fig. 5-36 shows the time series trends of the overall GHG emission from the MSW treatment and disposal system during 1992-2021 while both the actual data and sequential modeling estimates using the approach-2 of MSW discards are adopted during 1992-2004. Examining Fig. 5-22 and Fig. 5-36 simultaneously, the overall GHG emission from the MSW treatment and disposal system is kept at the same level by raising the incineration rate of MSW discards while the overall MSW discards almost double during 2005-2021 in the scenario analysis.

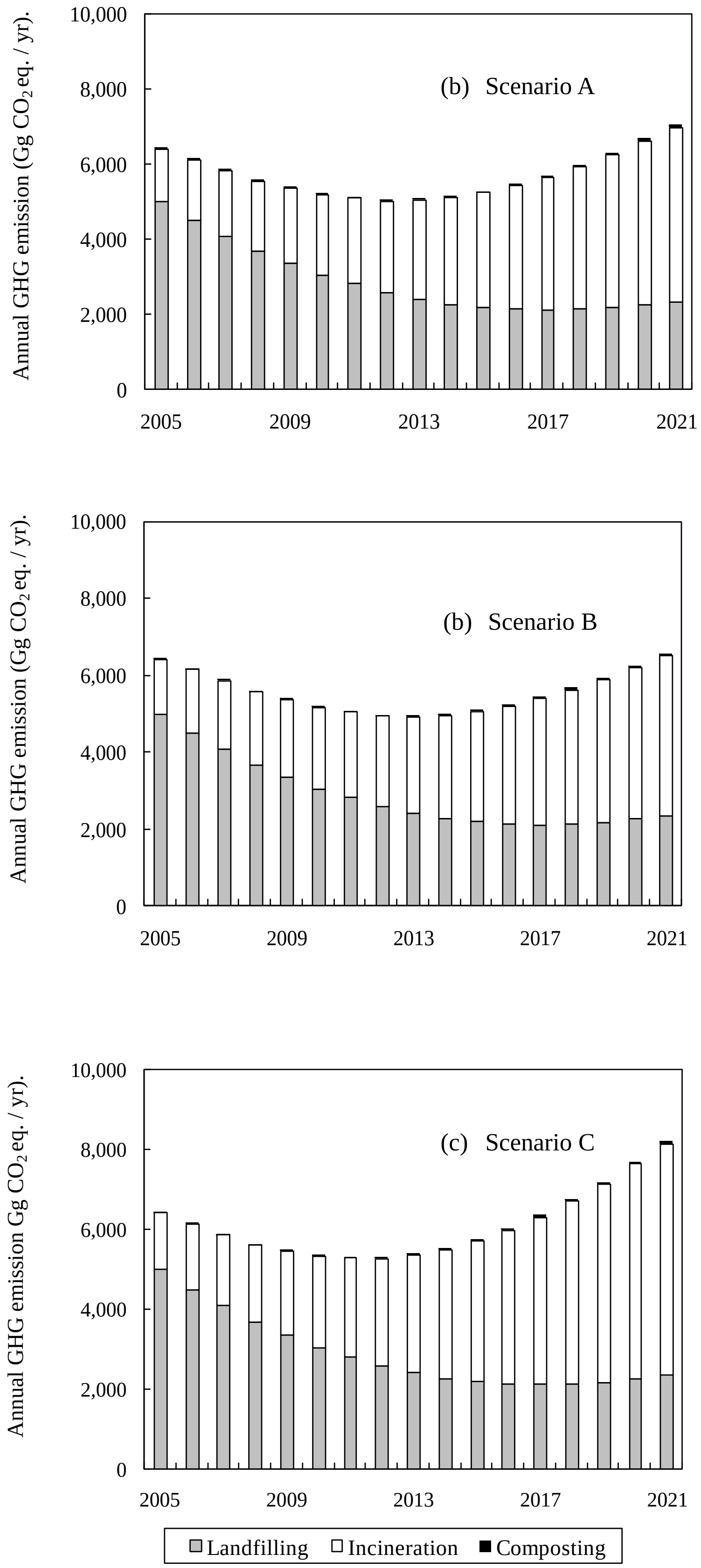

Fig. 5-35 Ex-ante forecasting of the GHG emission from the incineration of MSW discards in terms of MSW fractions.

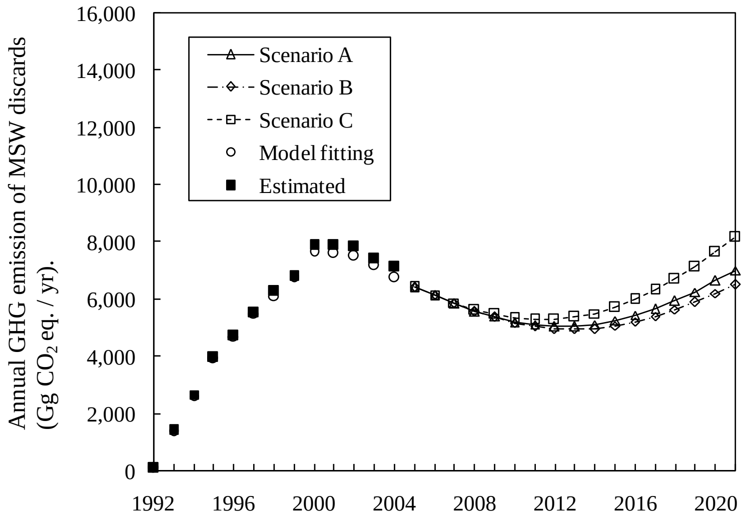

Fig. 5-36 Estimation and future projection of the GHG emission from the MSW treatment and disposal system.

Note: The "estimated" denotes the estimated GHG emission by using the true values of the MSW discards; **t**he model fitting denotes the estimation of the required capacity using the estimates, and the ex-post forecasts of the estimation model system of MSW discards during 1992-2004 while the ex-ante forecasts of the estimation model system are used during 2005-2021.

On the argument of the "environmental-friendly" MSW treatment and disposal technologies, from the perspective of preventing the global warming, the unit GHG emission rates for the three options in the scenario analysis are examined. The trends are consistent in the three scenarios. Taking outcomes from the Scenario C as example, Fig. 5-37 demonstrates the time series of the unit GHG emission rates of the three technologies.

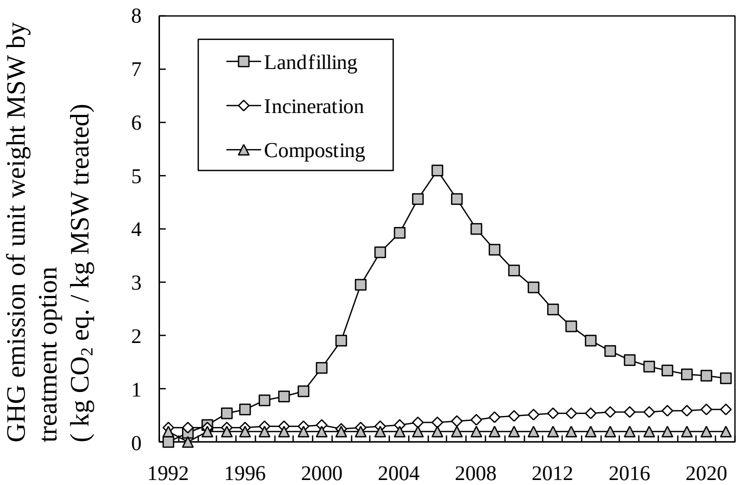

Fig. 5-37 Estimates of the unit GHG emission rate for landfilling, incineration, and composting during 1992-2021.

Although the unit GHG emission rate is associated with the input of MSW discards, the unit GHG emission rate for the landfilling is the highest among the values of the three technologies. Moreover, the behavior of the GHG emission for the landfilling is consistent with the assumptions of the FOD model since the peak of the unit GHG emission rate appears around the 14th year after disposal. Also, it is associated with the throughput and the composition in the current year as well. In addition, the unit GHG emission rate for the incineration is getting higher according to the higher composition ration of the plastic waste in the throughput of incineration. Actually, the waste composition is assumed the same in the landfill sites and the incinerators due to the availability of data. However, the waste composition will vary to a great extent since the new regulation published in 2006 order that the combustible MSW not be dumped in the landfill sites until it is incinerated (see Table 5-8).

This study focuses on the current treatment and disposal systems, but potential GHG emission during the reuse and recycling process of MSW fractions should be further considered in the extended study if the data is available. Even, the progress of MSW treatment and disposal system clines to use incineration as the main option of MSW treatment technology due to the limited land resources in some countries, Taiwan and Japan for example. However, such technology option is inconsistent with the argument of “bring back the organic waste to the soil”, which aroused more concern in recent studies (Marmo, 2008). From this point of view, organic matters of waste may be treated by composting rather than incineration since the unit GHG emission rates for incineration and composting are close to each other and much smaller than that for landfilling. However, the optimal technical options should be made by considering the constraints of land resources, administrative budgets, the resource-recycling issues, the optimal GHG emission, and the balance of ecologic systems.

To sum up, the annual GHG emission from MSW treatment and disposal system in Taiwan is estimated on the basis of the IPCC’s revised methodology, and its future projection can be obtained by using the estimation model system of MSW discards set forth here. Analysis results show that annual CO_2 eq. emission from MSW treatment and disposal system is about 2.86% of total CO_2 eq. emission in Taiwan in 2002. In addition, the analysis results suggest the incineration and composting seem to be cleaner technologies in MSW treatment, compared with the landfill disposal in the aspect of global warming. Moreover, paper waste and food waste contributes more than 80% of the GHG emission in the landfilling, and plastic waste contributes more than 90% of GHG emission from MSW incineration among the categories. Thus, concrete policy measures in associated with “3R” principles should be made for reducing the discards of paper waste, food waste, and plastic waste.

The results presented in the case study of Taiwan show that domestic technological parameters in the estimation of GHG emission are of particular importance in terms of the uncertainty of analysis results. Since most parameters are seldom available except recommended value in IPCC’s report, it is necessary for countries to develop domestic values for these parameters so that the estimation would be convincing for domestic assessment, particularly the ratios of moisture content for MSW fractions, which are necessary in the estimation the GHG emission during the incineration of MSW.

For the future application, by using the estimation model system of MSW discards, more concrete and environmental-friendly GHG reduction countermeasures in MSW management system can be considered in a comprehensive aspect. For example, the change of the consumption pattern can be analyzed through the sequential modeling and estimation procedures as the case study presented. In additional, potential GHG emission during the reuse and recycling activities of MSW fractions, e.g. the composting of recycled food waste, should be further estimated if the official database is available.

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Chapter 6 Conclusion and Future Works

As the industrialization and urbanization diffuse and popularize all over the world, people's lifestyle changes dramatically. However, such changes over the recent decades have brought about the phenomenon of "mass production, mass consumption, and mass waste discard". As more and more evidences suggest that the unsustainable pattern of contemporary consumption, associated with the individual's lifestyle, has been considered as one important driving factor for environmental loads. It is imperative to quantify the consumer's behaviour and its impact on the environmental loads, particularly on the increasing MSW discards. This study attempts to propose a holistic integrated socio-economic-environmental modeling system for the MSW management. The proposed methodology firstly estimates the individual's consumption expenditure, secondly quantifies the consumer's behaviour, and subsequently identifies its influences on the amount of MSW discards taking account for the policy interventions simultaneously.

To achieve the abovementioned objectives, the estimation model system of MSW discards is designed to model the waste conversion processes during the consumption, comprising (1) the consumption forecasting model, (2) the consumer's behavior model, and (3) the MSW discard model. The models are consecutively carried out in the Taiwanese case study where the economy is growing and the lifestyle changes rapidly.

The specialist and contributions of this study are: (1) establishing a detailed quantitative modeling system of the consumer's behavior; (2) clarifying the impacts of the consumer's behavior and policy interventions on MSW discard rate in terms of waste fraction simultaneously by developing an quantitative model; (3) facilitating and designing the MSW management system by using the backcasts, the estimates as well as the future projections (the ex-ante forecasting) of MSW discards generated by the models set forth in this study in terms of capacity planning of MSW treatment and disposal system and its potential on the GHG emission.

6.1 Conclusion and Outcome

The achievement and outcomes of the respective chapter is concluded as follows:

Chapter 1 makes an attempt to discuss the imperative issue on the relationship between the unsustainable pattern of the contemporary consumption, which is driven by the individual's lifestyle, and the increasingly serious environmental problems, especially the MSW generation and discards during the human consumption process. Since the quantitative modeling on such theme is hardly available, there is a crucial need to identify the impact of the consumption on the MSW discards, as well as the relevant influences on the MSW management system in terms of the capacity planning of the MSW treatment and disposal facilities and the impact of the MSW discards on the global warming. Afterward, the research objectives and the overall framework of this study are proposed.

In Chapter 2, the effects of the consumption on the fate of the MSW discards are discussed. The efforts made by the previous studies are reviewed. At the beginning, the relationship between the lifestyle changes and the environmental loads are exploited. Subsequently, potential influential factors of the MSW discards are qualitatively clarified through. In addition, the earlier established quantitative models of the MSW generation are compared, and the efficient quantitative methods are proposed due to the study purposes. Consequently, a new conceptual quantitative modeling framework on the waste conversion during the consumption process is proposed.

Chapter 3 is to develop a holistic and practicable estimation model system, based on the relevant theories, substantially quantifying the waste conversion process during the consumption. Firstly, the motivation of the utilization of the econometric modeling techniques and the procedures for developing econometric models are described. The entire estimation model system of MSW discards comprises (1) the consumption forecasting model, (2) the consumer's behavior model, and (3) the MSW discard model. Afterward, the detailed formulation, the theoretical basis, and the assumptions of the abovementioned models are respectively derived. By using the econometric techniques, the estimation model system started at developing the consumption forecasting model simulating the individual's overall consumption expenditure based on the macroeconomic and socioeconomic indicators with a single-equation regression model.

Subsequently, the consumer’s behavior model, analyzing the consumer’s preferences in terms of the lifestyle changes, is to be as a two-layer structure based on the hierarchical analysis of per capita consumption expenditure, comprising of the linear expenditure system (LES) model and the multinomial logit (MNL) model. Consequently, the MSW discard model, representing the conversion process from commodities into waste during the consumption, is built via the multi-equation regression model (the simultaneous equation system (SES) model). Important policy implications can be found in the respective model. Furthermore, by coupling the models, the estimation model system of MSW discards can analyze the effects of the consumption and the MSW policy measures on the MSW discards in terms of waste fractions, simultaneously.

As for the application of the estimation model system on the MSW management system, two important issues on the MSW treatment and disposal system, the capacity planning as well as the reduction on its GHG emission, are involved in Chapter 4. Evaluation procedures are proposed to connect the outputs of the estimation model system of MSW discards with the estimation of two issues. Therefore, the impact of the individual’s consumption, associated with the lifestyle changes, on the MSW management system can be identified. In keeping with the research objectives, the holistic evaluation of the effects of the consumption on the MSW management system can be achieved.

In Chapter 5, the proposed models are consecutively carried out in the Taiwanese case study where the economy is growing and the lifestyle changes rapidly. The major accomplishments are as follows:

(1) The socioeconomic indicators reflecting the lifestyle are preliminarily analyzed, and they are found to be highly correlated, designating the existence of the intrinsic influential factor of the lifestyle. Furthermore, the “aging” phenomenon is significant.

(2) The MSW management system and the supportive regulations are reviewed and preliminarily evaluated both on the national and local levels.

(3) The consumption forecasting model is developed based on the adaptive expectation permanent income hypothesis, well describing the consumption

pattern in Taiwan, with an additional explanatory variable of the "unemployed rate".

(4) Both the LES model and the MNL model show good performances in modeling the consumer's behaviour; the elder population ratio and the individual' saving rate are significant for most equations in the LES model and the MNL model while the socioeconomic variables are highly correlated.

(5) The marginal budget shares of the consumption categories estimated by the LES model suggest that in Taiwan the individual's consumption expenditure on "food" and "housing" occupy the most portions in the individual's subsistence level of consumption while these on "housing", "medicines & medical care", and "amusement & education" have more significant influences on the consumer's preferences in the non-subsistence level of consumption.

(6) The individual's subsistence level on the consumption expenditure is close to or even lower than the minimum legal labor wage, implying that the actual purchasing power for the low-income individual is quite limited.

(7) As for the MSW discard model, the results estimated by the SES approach is superior to these by the OLS method, implying the inter-correlation among the MSW fractions should be considered in the modeling work.

(8) Using the SES modeling approach, the outcomes from the SUR estimation clearly identify the impacts of the consumption items and the relevant MSW policy measures on the MSW discards in terms of waste fractions. Results of the analysis indicate that the per capita consumption expenditures on "food", "household appliances", and "amusement & education" are the main driving factors for the discards of the majority of waste fractions in Taiwan from 1992 to 2004. Such results are of particular importance facilitating the consumer's behavior and promoting the sustainable lifestyle. In addition, the existing MSW policy measures can be improved and more efficient ones can be proposed in a socio-economic-environmental aspect.

(9) Coupling the models, the estimation model system can simulate the MSW discards in terms of the quantity and the composition only with several

exogenous variables, including the per capita GDP, the unemployed rate, the elder population rate, the individual’s saving rate as well as the MSW policy variables. All the backcasts, estimates, ex-ante forecasts, and the ex-ante forecasts (future projections) of per capita MSW discards by waste fraction can be generated given the values of exogenous variables via the estimation model system.

(10) Through validating the models in the Taiwanese case study, the estimation model system can provide accurate estimates and catch the major trends of the interested variables. Thus, it can serve as a decision support tool simulating the interaction among the consumption, MSW policy measures and the amount of MSW discards in terms of waste fractions. Three scenarios representing the different consumption levels are subsequently simulated with the estimation model system of MSW discards. The potential impacts of the increasing consumption on MSW discards by waste fraction are quantified, and important policy implications are further made.

(11) With the ex-ante forecasts of MSW discards by waste fraction based on the assumed scenarios, the possible ranges of demanded capacities of the MSW treatment and disposal system in Taiwan up to 2021 are further projected considering the socioeconomic changes and the policy effects. Such information can provide necessary information for the policy decision-makers. In addition, concrete policy measures are suggested.

(12) Based on the results of the scenario analysis, the required capacity for the lanfilling is insufficient (even considering the low consumption scenario) during 2006-2021. The decision-makers should progressively enlarger the level of the disposal capacity for both MSW and the incineration ashes. Also, more efficient policy measures on reducing the amount of MSW discards can be considered. Besides, procedures in terms of the sophisticated covering operation should be further adopted at existing landfill sites for stabilizing the dumped incineration ashes, and specific landfill sites for the incineration ashes should be further established soon.

(13) Based on the results of the scenario analysis, the required capacity for the incineration is not crucial until 2015 (as for the high consumption scenario), compared with the treatment capacity of the incineration in 2006. Hence, new incinerators are not essential in the near future, and the existing incinerators have the remaining capacity to treat some general industrial waste to maintain their optimal operation condition. However, cross-prefecture MSW treatment network should be established to improve the incineration.

(14) Using the historical records of MSW composition and quantity, the GHG emission from the MSW treatment and disposal system in Taiwan is estimated with the IPCC 2006 methodology. Moreover, paper waste and food waste contribute more than 80% of the GHG emission in the landfilling, and plastic waste contributes more than 90% of GHG emission from MSW incineration among the categories. Thus, concrete policy measures in associated with “3R” principles should be made for reducing the discard of paper waste, food waste, and plastic waste, e.g. reducing excess consumption on such commodiites, as well as reusing and recycling them during the economic avtivities.

(15) Analysis results show that annual CO_2 eq. emission from MSW treatment and disposal system is about 2.86% of total CO_2 eq. emission in Taiwan in 2002. In addition, the analysis results suggest incineration and composting seem to be cleaner technology options comparing to landfill disposal in the aspect of preventing global warming. However, more detailed data for MSW composition and characteristics in Taiwan is requireded to conduct the estimation procedure provided by IPCC 2006 methodology.

(16) Although the incineration is getting popularized in Taiwan due to the limited land resources, however, such technology option is inconsistent with the argument of “bring back the organic waste to the soil”, which aroused concern in recent studies. From this point of view, organic matters of waste may be treated by composting rather than incineration since the unit GHG emission rates for incineration and composting are close to each other and much smaller than that for landfilling. However, the optimal technical options should be

made by considering the constraints of land resources and administrative budgets, the resource-recycling issues, the optimal GHG emission, as well as the balance of ecologic systems.

(17) Based on the results of the scenario analysis, the results show that the overall GHG emission from the MSW treatment and disposal system is kept at the same level by raising the incineration rate of MSW discards although the overall MSW discards almost double during 2005-2021 in the scenario analysis. Thus, the incineration should be comprehensively adopted for the majority of the treatment of MSW discards with well equipments for pollution prevention in Taiwan.

To sum up, this study describes a methodology and validates it by a Taiwanese case study for quantifying the relationship among the MSW discards, the individual's consumption expenditure, as well as the environmental policy measures. The established estimation model system can generate precise estimates of per capita MSW discards in terms of waste fractions, and thus can be a useful decision support tool for the decision-makers to examine the impact of the individual's consumption on the environment in the process of civilization. Since the consumer's behavior and its influences on the MSW discards are analyzed, a sustainable lifestyle can be formed by reducing the potential "excess consumption" in the individual's consumption expenditure. Moreover, tangible strategies involving the ideas of "dematerialization", "slower consumption", and "ecological modernisation" can be made. The findings of this study will contribute to the promotion of a low waste society on (1) making strategies facilitating the consumer's behavior based on the quantitative relationship between individual's consumption and MSW discards in terms of the sustainable consumption and lifestyle; (2) planning of MSW management system for (a) the capacity forecasting of MSW treatment facilities, (b) the estimation of the relevant environmental loads, e.g. the emission of greenhouse gas and leachate, from MSW management system, and (c) the estimation of potential resources of waste within the MSW discards. The design of concrete policy measures can be further achieved through the established models in terms of waste reduction, recycling programs, recovery and conservation of the soil layer along with the biosphere, capacity planning of MSW treatment and disposal system as well as the prevention of global warming. The findings of this study will contribute to the policy design towards the sustainable lifestyle and the low waste society.

6.2 Future Works

This study makes an attempt on establishing a holistic methodology on modeling the relationship among the MSW discards, the individual's consumption expenditure, as well as the environmental policy measures. As for the model development, some efforts should be improved continuously:

(1) In this study the models are established on a national level, the entire Taiwan society is viewed as an aggregate group in the case study. In fact, the inner disparities of the lifestyle and the consumer behavior may exist between the urban and rural regions. Thus, such diversities of the abovementioned socioeconomic attributes are not considered in the national-level modeling work. From another viewpoint, a comparison of the model results for different countries or regions will be meaningful.

(2) As for the consumer's behavior modeling in terms of the lifestyle analysis, the individual's time expenses has not been considered in the current models due to the deficiency of the required detailed data. The time expense may further be considered in the modeling work. In addition, the modeling of time-variant consumer's preferences can be further studied in the future works.

(3) In modeling the waste conversion process during the consumption, insufficient data limits the model capability to describe the characteristics of the waste conversion process. Detailed data in terms of the life span of the products in the households and a detailed database for the characteristics of the consumption process is required. Even, more detailed waste streams, e.g. the container and packaging waste, can be further estimated by the established models, given the ratios of the specific waste streams among the fractions of MSW discards. More

delicate policy design can be simulated and achieved.

(4) The country-wide estimation model system established in the case study of Taiwan is difficult to account for the effects of local MSW policy measure. But it can be achieved in a local-scale modeling work. In addition, the effects of some prospective policy measures cannot be accounted for in the current modeling work, but it can be evaluated by using the presented methodology.

Except for the abovementioned works, a comprehensive and credible database in terms of socioeconomic indices and waste characteristics is required for the quantitative modeling of this study. Several items should be particularly remarked as follows:

(1) Consistent and reliable MSW composition data is essential for the model development in this study. In particular, the moisture content of the respective waste fraction seems to be an important parameter in the estimation of the MSW discards and the GHG emission from MSW treatment and disposal system while such fundamental data is hardly available in the official records for most countries. Such data should be highlighted in the MSW database.

(2) As for the capacity planning of MSW treatment and disposal system, the detailed information for the actual throughput and capacity of the existing facilities in operation is limited for the further study. Routine surveys on the capacities of MSW treatment and disposal facilities should be conducted in support of the decision-making of MSW management.

(3) The IPCC 2006 methodology is nowadays recommended in the estimation of the GHG emission from the MSW management system. However, domestic parameters for the estimation are hardly available for many countries. It is imperative to develop the domestic parameters for the estimation methodology.

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